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FTFF-TM-58-12
April 1958

AFFTC Technical Memorandum

EVALUATION of TAKE-OFF and LANDING FACILITY

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6 EVALUATION OF TAKE-OFF AND LANDING FACILITY,

~~ETFP-TM-58-12~~

A~~pril 1958~~

10 BY

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Project Engineer

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April 1958

This memorandum has been reviewed and is approved.

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CHARLES W. OLIVER, Chief
Technical Facilities Division

EVALUATION OF THE AIR FORCE FLIGHT TEST CENTER
TAKE-OFF AND LANDING FACILITY

ABSTRACT

Static and Dynamic Tests were conducted to evaluate the AFFTC Take-Off and Landing Facility and to establish the degree of accuracy that can be expected when the Facility is employed to obtain aircraft performance data during flight testing. The most accurate position data is obtained when a two-station Askania Theodolite Solution is employed. It was also found that, under certain conditions set forth in this report, the accuracy of the data resulting from a single station Askania Theodolite Solution approached that of the two-station solution.

The Facility, which was constructed under ARDC Project 6900, Task 69000, is described and the results of the evaluation test are presented.

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INTRODUCTION

The principal aim of flight testing is to collect reliable data which may be used to develop an airplane and its particular systems as well as to predict its performance under standard and non-standard conditions. Among the more important parameters are those of the Take-Off & Landing Phases, particularly such items as:

a. Length of ground run on take-off for different weights and configurations of the aircraft.

b. Distance to clear a 50-foot high obstacle, take-off or landing.

c. Indicated and true air speed at lift-off point, at 50 foot altitude and at touchdown.

d. Acceleration or deceleration during ground run.

e. Rate of sink on landing.

Since it is impossible to obtain and record all of this data within an operational airplane to the accuracy required, an independent ground based system must be employed. The system or facility employed at the Air Force Flight Test Center consists of two identical stations, one of which is shown in Figure 1, Appendix "A". The stations are located approximately one mile from the longitudinal centerline of the runway and 8690 feet apart. Each station is designed to accommodate two tracking instruments and synchronisation of all data is obtained by the use of the AFFTC Precision Askania Range System of Electronic Timing (PARSET).

Geodetic positions of both stations and all target boards, with respect to the main runway, were determined by a first order survey conducted by the National Engineering Company, Los Angeles, California, on Contract AF 04(611)-2819. For reference purposes a summary of the survey data is contained in Appendix B, Geodetic Data.

Prior to the installation of the present system described in this report, take-off and landing performance data was obtained by using a temporary instrument station located on the Edwards AFB Control Tower, approximately 50 feet above the ground. This single interim station was inadequate to provide complete data of the required accuracy for several reasons:

a. Complete coverage of the entire runway could not be obtained.

b. Instrument was subject to vibration and instability of the Control Tower structure.

c. Reliability and accuracy of the tracking instrument was reduced because of exposure to elements.

EQUIPMENT

The present equipment used to instrument the Take-Off & Landing Facility consists of one Askania Cine-Theodolite, one Akeley Cine-Theodolite and one PARSET timing installation located in each station together with the necessary radio equipment to provide two-way communications with test aircraft using the Facility.

The Askania Cine-Theodolite is a precision field type tracking instrument capable of measuring azimuth and elevation angles and recording these values on 35mm film while simultaneously photographing the aircraft in the same frame of film. Figure 2, Appendix "A" is a sample of data recorded by the Askania Cine-Theodolite, with the azimuth angle shown in the upper left corner and the elevation angle in the upper right corner. The photograph of the target is used to measure the angular difference between the recorded angles (optical axis of the theodolite) and the line of sight to a reference point on the aircraft. This difference is then added algebraically to the recorded angles. This instrument operates at a maximum of four data frames per second. The 100 cm (40 inch) focal length lens employed on the Take-Off & Landing Askania Theodolites provides a field of view of $1^{\circ}23'$ x $2^{\circ}04'$ or a minimum area of 126 feet x 186 feet at a point on the runway closest to the instrument. The field of view at other points along the runway is shown in Fig. 3, Appendix A. The angular resolution of the data recorded on the film is .002 degree or 7.2 seconds of arc.

The Akeley Cine-Theodolite is a tracking instrument similar to the Askania, but of smaller size and lesser accuracy. It is equipped with a 27-inch focal length lens and will operate at frame rates of 4 to 20 per second. Angular data in this instrument is presented in the form of counter readings which are recorded on the film adjacent to the target frame. For a sample of this type of data see Figure 4, Appendix A. The angular data recorded by this instrument can be accurately read to .1 mil or 20.25 seconds of arc. These instruments, when equipped with 27 inch focal length lenses, provide a field of view of approximately 29 x 26 mils or an area of 147 ft x 132 ft at a point on the runway closest to the instrument.

The AFFTC PARSET Timing Equipment is used to receive timing signals from the Askania Master Control Station. These timing signals are used to trigger the data flash lamps and the shutters of both Askania Theodolites simultaneously, print the time of exposure in binary code on each frame of Askania Theodolite data and advance the time counter of the Akeley Theodolites simultaneous with the flash and shutter of the Askania Theodolites. The binary code indicating the time of day as 11 hours, 42 minutes and 17.25 seconds can be seen at the lower edge of the sample Askania data frame, Figure 2, Appendix A.

A standby timing system, consisting of an electronic intervalometer, has been installed at each station as a back-up timing system control in case of equipment failure at either the Askania Master Station or in the electronic timing equipment at the Take-Off and Landing Stations.

USE OF SYSTEM

The normal employment of theodolites to obtain space position data requires the use of at least two instruments located at accurately surveyed positions such as shown in Figure 5, Appendix A. In this particular employment, the only known values are the length of the baseline and the X, Y and Z coordinates of each station. Point T is computed by triangulation using the known baseline A-B and the measured angles G_I and G_{II}. Altitude h is computed by solving either of the two right angle triangles, AZT_3 or BZT_3. Details of the complete data reduction process for multiple station solution are given in Appendix D.

In addition to the multiple station solution described above, the fixed perpendicular distances, P_E and P_W, Figure 6, Appendix A, allow take-off and landing performance data to be obtained by using only one station. The use of single station solutions, however, imposes several requirements that must be met to obtain accurate data.

a. Test aircraft must stay on the centerline of the runway. Any deviation from the runway centerline will result in a data error proportional to the deviation and the distance along the runway. As an example, a 5-foot deviation from the centerline would not create any error when the aircraft was on the station perpendicular (P_E, P_W), but when at a point half-way down the runway, the error in distance along the runway would be approximately equal to the deviation.

b. If the data area extends more than 8000 feet down the runway, both stations must be used and a transition made from one station to the other during the overlap area shown in Figure 5, Appendix A.

The solution of single station data requires only the solution of succeeding right angle triangles such as shown in Figure 6, Appendix A, wherein the perpendicular P_E or P_W is a constant value and each succeeding value of A_W or A_E is used. The complete single station solution formula is contained in Appendix D.

SINGLE STATION VS TWO STATION SOLUTIONS

The choice of single or two station solution is a decision that must be made by the project engineer requesting the data based on the following conditions:

a. Accuracy of Data.

As reflected elsewhere in this report, the greater accuracy is obtained by using a two station solution. If the optimum accuracy of the present system (two-station solution) is not required, a single station should be used, thereby minimizing the data reduction workload as shown in paragraph b below.

b. Time Required for Data Reduction.

The processing and computation of raw film data to position and velocity information is the most time consuming step in the delivery of usable data to the data requester. The average data processing times are as follows:

FIGHTER TYPE AIRCRAFT

Solution	Take-Off or Landing	Take-Off and Landing
1 Station	2 days	3 days
2 Station	3 days	4 days
BOMBER OR CARGO TYPE AIRCRAFT		
1 Station	3 days	4 days
2 Station	4 days	4 days

Thus the data requester must balance the desired accuracy of the test data against the time required to process the information and return to the requester.

DESCRIPTION OF TESTS AND RESULTS

Tests of the AFFTC Take-Off and Landing Facility were conducted on 2 November 1957 to determine the static and dynamic accuracies of the system. A van type truck, as shown in Figure 2, Appendix A, equipped with two lights located 19.5 feet and 9.53 feet above ground level was used as the target for all tests.

STATIC TEST

During the static portion of the test, the truck was first positioned at the east end of the runway and then at 1000 feet intervals along the runway until the length of the runway had been traversed. This resulted in data being taken at a total of sixteen points. The truck was positioned on the centerline and as close as possible to the 1000 feet interval markers. Any offset from the markers was measured and recorded by an observer in the truck.

As all available information indicate that the 1000 feet interval markers are accurately located, the following results, based on this assumption, were obtained:

2 STATION SOLUTIONS

Askania	0.54 foot, Average error	1.50 feet maximum error
Akeley	0.96 " " "	3.64 " " "
West Askania		
Full Runway	1.25 feet Average error	5.97 feet maximum error
7 to 15,000	0.66 foot " "	1.39 " " "
East Askania		
Full Runway	0.77 foot Average error	2.18 feet maximum error
0 to 8000	0.57 " " "	2.18 " " "
West Akeley		
Full Runway	1.38 feet Average error	4.82 feet maximum error
7 to 15K	1.00 foot " "	2.20 " " "

East Akeley

Full Runway	0.57 foot Average error	3.58 feet maximum error
0 to 8000	0.40 " " "	0.80 foot " "

Complete results of this portion of the test are shown in Figures 1 and 2, Appendix C.

Data was also taken to determine the resultant error, if the aircraft was off the centerline and a single station computation was made. The target truck was positioned at the north and south edges of the midpoint of the runway. The possible errors indicated by this test are shown in Figure 3, Appendix C, and verify previous theoretical calculations, Figure 4, Appendix C.

A first-order survey computed the elevation or altitude of Data Point No. 0 (east end of runway) to be 2281.0 feet. Construction details specified a slope to the east of -0.140% ±0.002% or -21 feet ±0.3 foot in the 15,000 feet length of the runway. Inspection of the runway after construction revealed the slope to be within the specified tolerances with slight deviations occuring in the individual sections of the runway due to varying conditions at the time of pouring each section. With this information the computed two station Askania and Akeley data was compared with the theoretically correct elevations along the runway and the results are shown in Figure 5, Appendix C. Due to the single station solutions not providing a computed height above sea level, but rather a relative height above the first data point, these solutions were not included in the comparison above. It is possible, however, to compare the slope of the runway as computed by both single and two station solutions. This comparison is found in Figures 6 and 7, Appendix C.

It is readily apparent that the smoothest curve and the one closest to the 0.140% standard is provided by the two (2) station Askania solution. Of the single station solutions, the smoothest curves are provided by the Askania data.

The accuracy with which the Askania and Akeley systems could measure a known distance was determined by comparing the data computed by both systems on both lights on the target truck. The measured distance between the lights was 9.9 feet. The tabular and graphic presentations of this comparison are shown in Figures 5 and 8, respectively, of Appendix C. The maximum deviations from the known value were 0.82 foot for the Askania data and 1.5 feet for the Akeley data.

Offset data, see Figure 7, Appendix A, was recorded at each end of the runway, as well as at data points located 4000 feet, 7000 feet and 11,000 feet from the east end of the runway. This data was for the purpose of determining if any error would result if the operator did not keep the target centered. Inspection data on the particular lenses show the lenses to be linear across the field of view, therefore, the errors shown below are contributed by: (a) Small inaccuracy in the film reading equipment and/or (b) Inability of the film reader to select the same point on the target every frame. This test indicated the following errors between the offset target data and the data computed with the target in the center of the field of view:

2 STATION SOLUTIONS

	Average Error	Maximum Error
Askania	0.86 foot	1.50 feet
Akeley	1.24 feet	2.85 feet

SINGLE STATION SOLUTIONS

	Average Error	Maximum Error
West Askania	0.83 foot	2.07 feet
East Askania	0.35 foot	1.52 feet
West Akeley	2.68 feet	11.36 feet
East Akeley	0.82 foot	1.55 feet

DYNAMIC TEST

The dynamic portion of this test was performed by driving the target truck at a constant speed of approximately 30 miles per hour down the centerline of the runway and recording data with all instruments during the time the target truck was traveling from the 7000 feet marker to the 9000 feet marker. Data for a period of 30 seconds in this area was reduced and the velocity data computed from both the Askania and the Akeley Theodolite data is presented in Figure 9, Appendix C, and shown graphically in Figure 10, Appendix C.

From this graphical illustration it is readily apparent that the velocity data computed from Askania data is considerably smoother than that computed from Akeley data.

The maximum velocity changes between points as shown by these curves are:

2 Station Askania Solution	.63 foot per second
2 Station Akeley Solution	4.37 feet per second
1 Station Askania (West) Solution	1.56 feet per second
1 Station Askania (East) Solution	1.04 feet per second
1 Station Akeley (West) Solution	3.10 feet per second

1 Station Akeley (East) Solution	5.17 feet per second

When 3 point smoothing was applied to the velocity curves shown in Figure 10, Appendix C, the maximum difference between the raw velocity curve and the smoothed curve was:

2 Station Askania	0.35 foot per second
2 Station Akeley	2.65 feet per second
1 Station Askania (West)	0.87 foot per second
1 Station Askania (East)	0.68 foot per second
1 Station Akeley (West)	2.06 feet per second
1 Station Akeley (East)	3.10 feet per second

REPEATABILITY OF DATA

Film data from the dynamic portion of the evaluation test was also used to determine the repeatability of different Data Reduction personnel in reading the film. Figure 9, Appendix C, also shows a tabular comparison for the computed data that resulted from four different persons reading the same raw Askania and Akeley data. From results of this reading test, it is obvious that the readability of the film is very good, as in the majority of cases the spread of four different computed 2 station solutions was approximately 0.2 to 0.3 foot per second for the Askania data and 0.3 to 0.4 foot per second for the Akeley data.

CONCLUSIONS

The following conclusions are presented, based on the results of this evaluation:

a. The most accurate position data on an aircraft using the Edwards AFB runway for take-off and/or landing will be obtained when a two station Askania Cine-Theodolite solution is employed. The accuracy of the data will be better than ± one (1) foot. Data of comparatively equal accuracy will be obtained by a one station Askania solution, provided the aircraft does not deviate from the centerline of the runway more than one (1) foot, and the take-off and climb to 50 feet altitude or the descent from 50 feet altitude and the landing are completed in the half of the runway closest to the station that is used.

b. If a single station solution is employed and a deviation from the centerline does occur, the resultant error in the computed position of an aircraft along the runway will be proportional to, but less than the deviation during the time the aircraft is in the half length of the runway closest to the station that is used.

c. Altitude data of an aircraft during a take-off and/or landing can be computed from two station Askania Cine-Theodolite data to an accuracy of better than ± one (1) foot. If a single station solution is employed, any deviation from the runway centerline is reflected in the altitude data, proportional to the deviation and the altitude of the aircraft.

d. Accuracy of the computed data is not adversely affected by the target being off-center in the data frame. The average error that resulted when the target was at either extreme edge of the data frame was less than one (1) foot.

e. Without any smoothing applied, velocity data can be obtained by the Askania Cine-Theodolite to an accuracy of ±1.5 feet per second. With three point smoothing applied, the accuracy is increased to ±0.9 foot per second. As the velocity variations indicated above are a result of error in determining the distance between data points, the variations will remain at this value and will not increase with higher velocities.

f. The ability of Data Reduction personnel in reading data from film is excellent. Magnitude of spread in the final data as a result of different persons reading the same raw data is insignificant.

RECOMMENDATIONS

The following recommendations are made:

a. That the use of Akeley Cine-Theodolites be discontinued and that a second Askania Cine-Theodolite be installed in each tower.

b. That a higher frame rate camera mechanism be installed in the Askania Cine-Theodolites as soon as possible. Until these mechanisms are available, it is recommended that 16mm movie cameras, with time correlation, be used to accurately determine the point of touchdown or lift-off.

c. As an additional improvement, aided tracking and operator seats be installed in the towers to reduce the tracking error, which in turn would reduce the data reduction time.

APPENDIX A

ILLUSTRATIONS

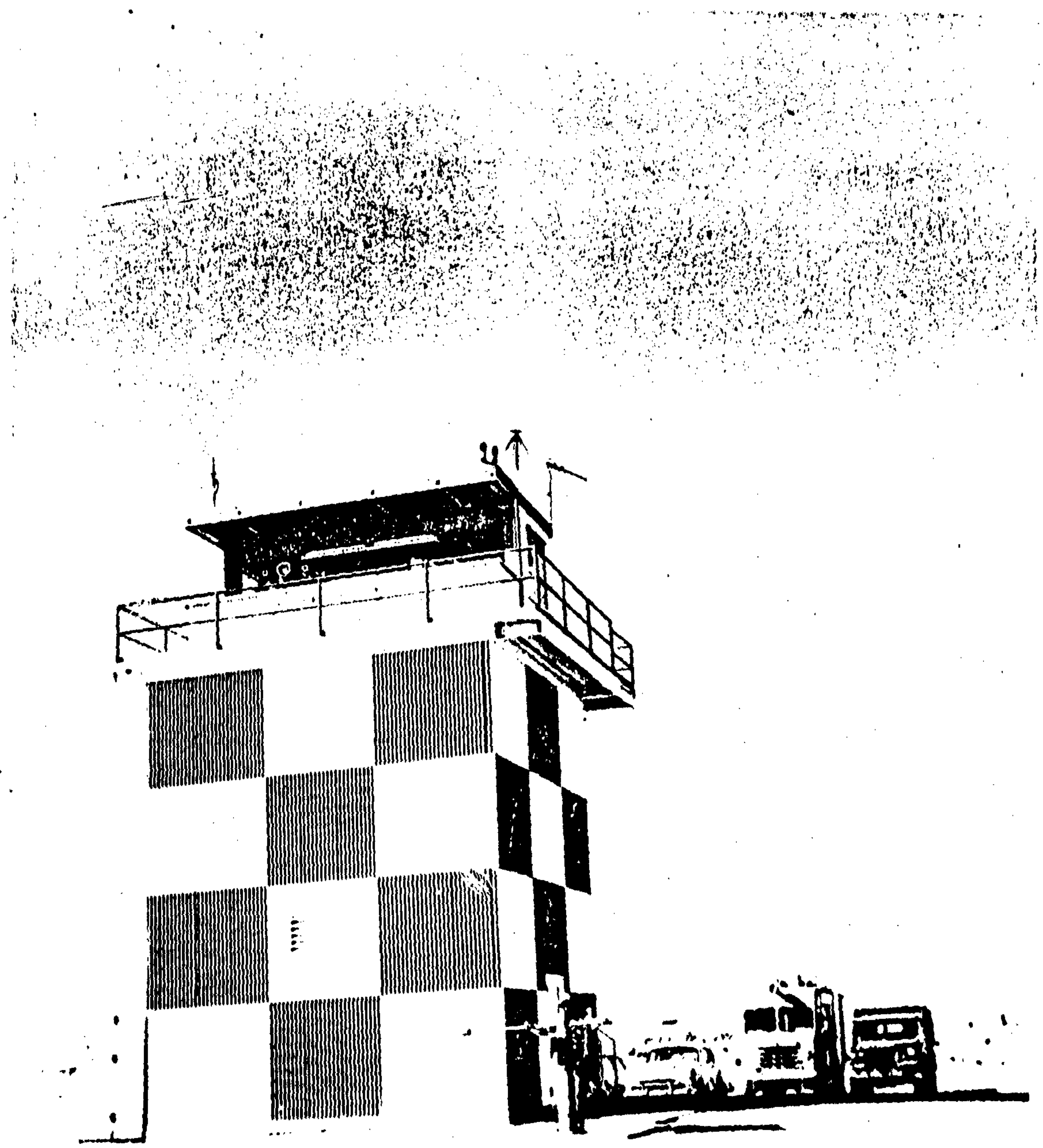


FIGURE 1, APPENDIX A
WEST TOWER, TAKE-OFF AND LANDING FACILITY
FRONT VIEW

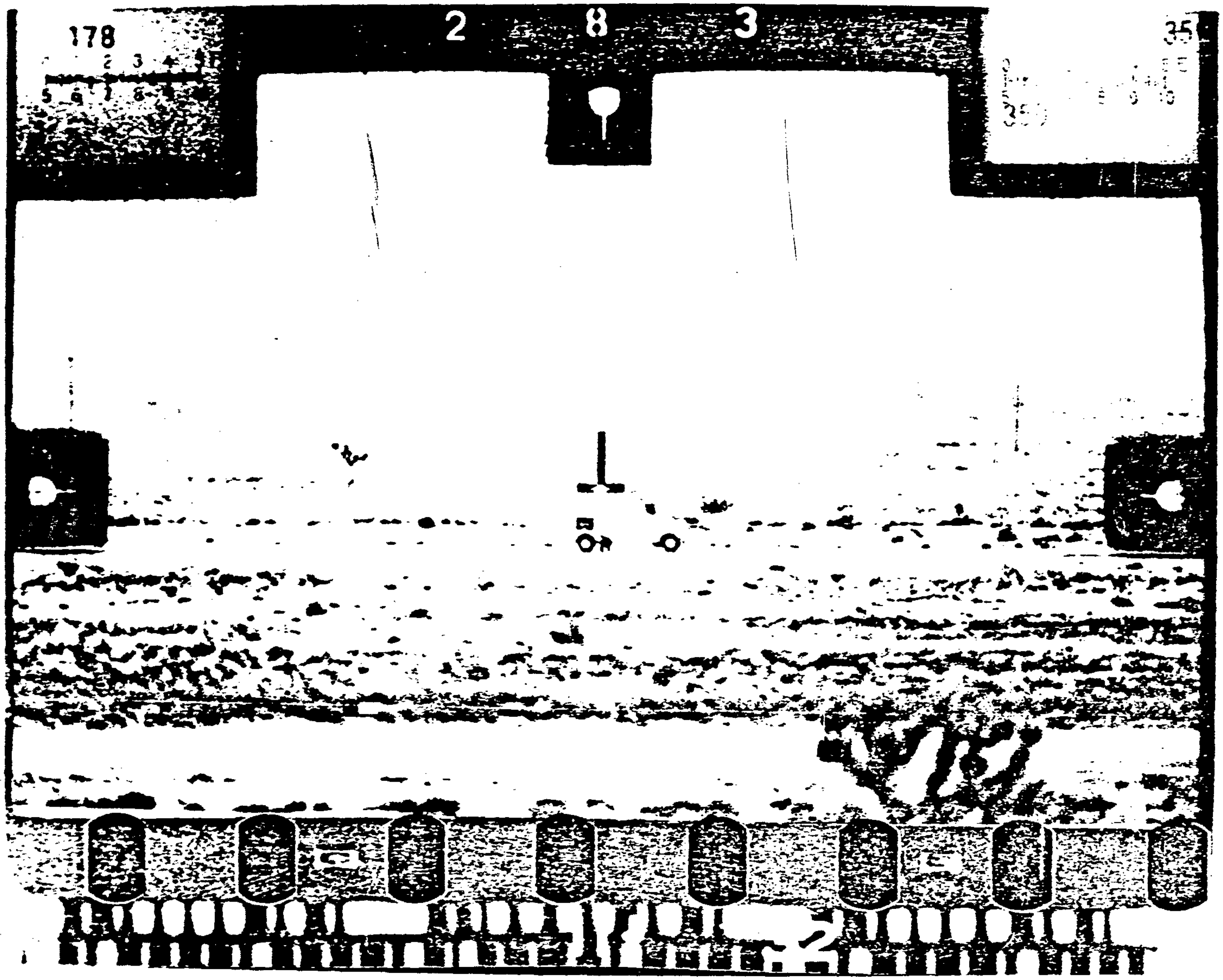


FIGURE 2, APPENDIX A
ASKANIA CINE-THEODOLITE FRAME

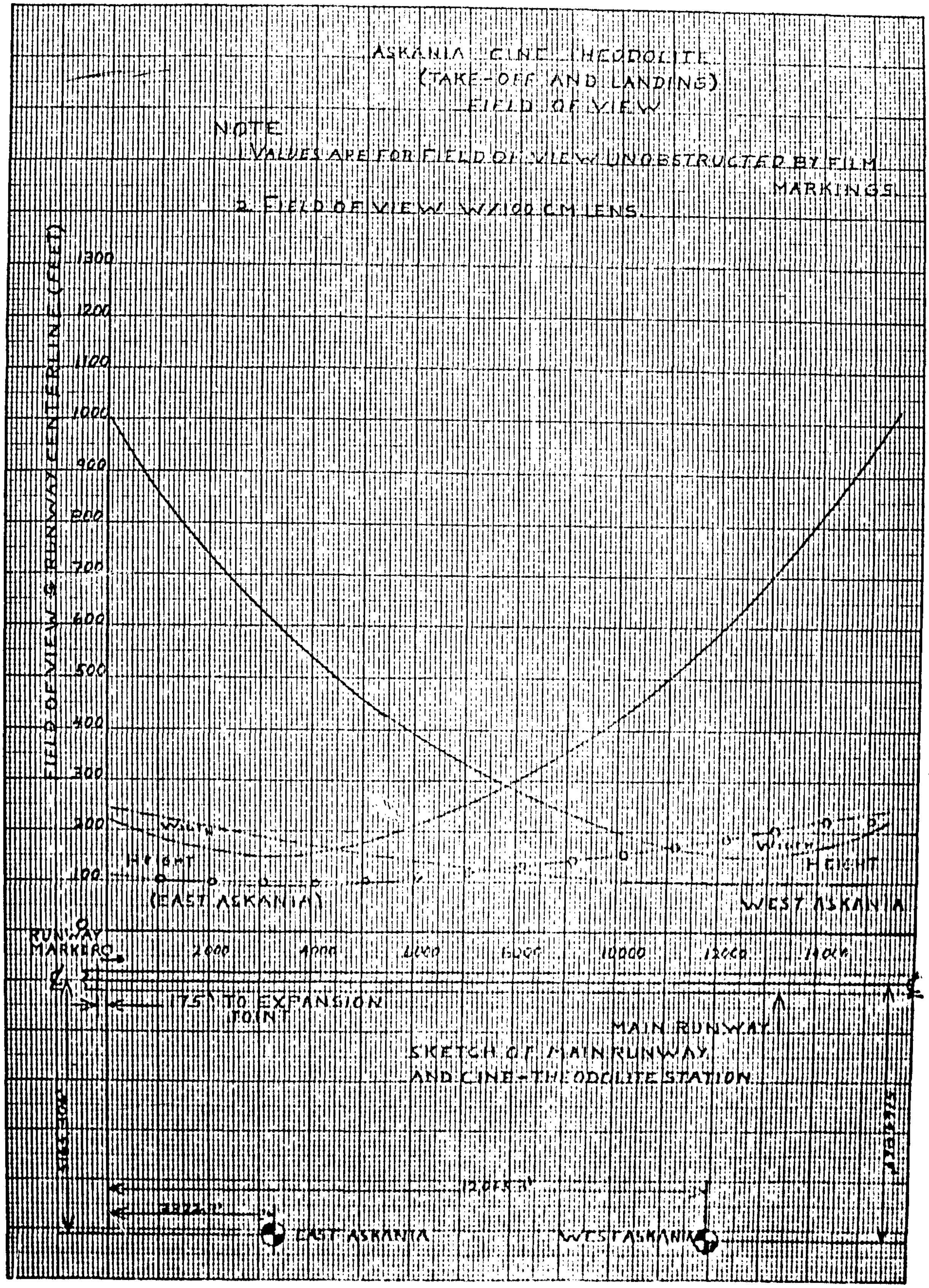


FIG 3
APPENDIX A

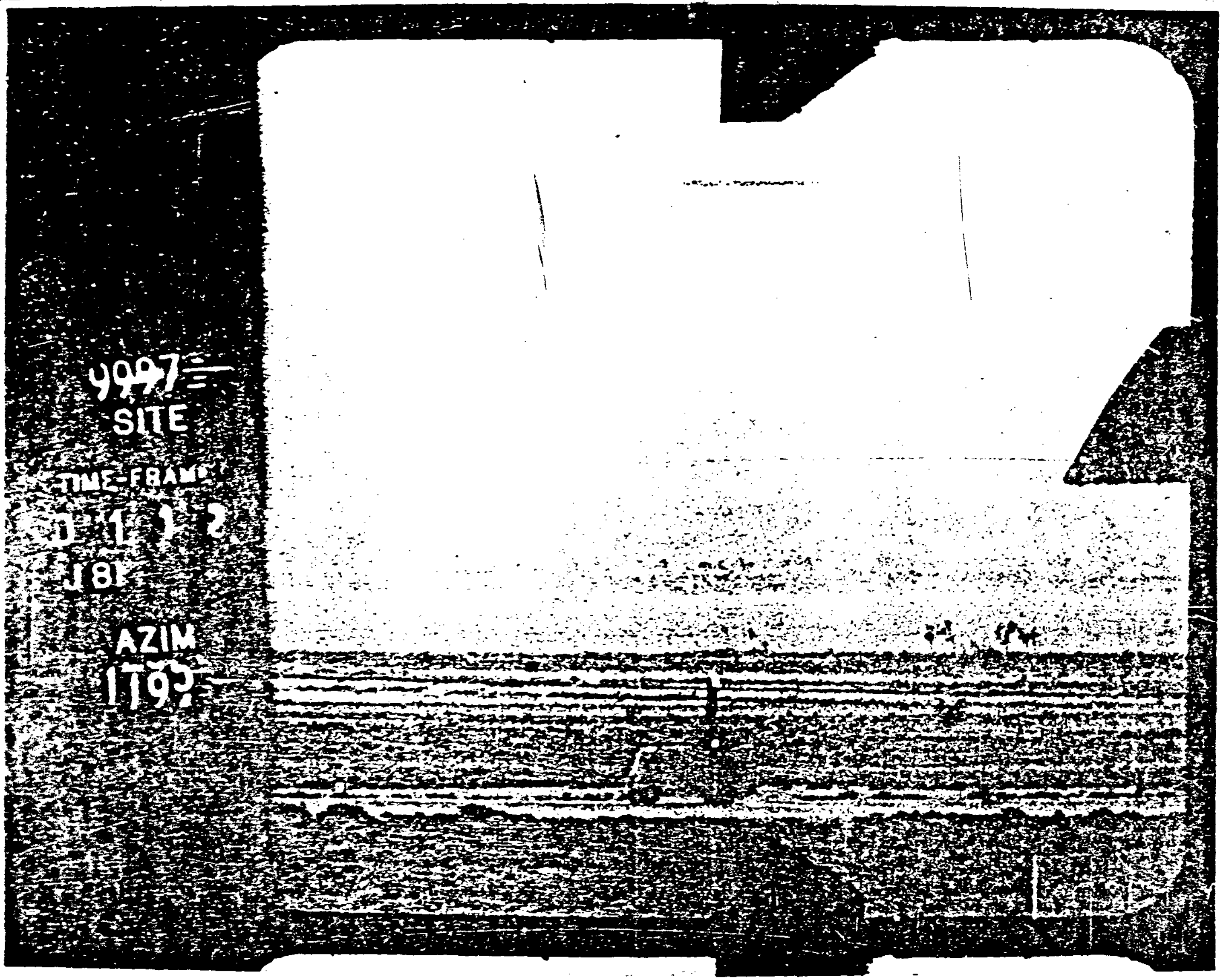


FIGURE 4, APPENDIX A
AKELEY CINE-THEODOLITE FRAME

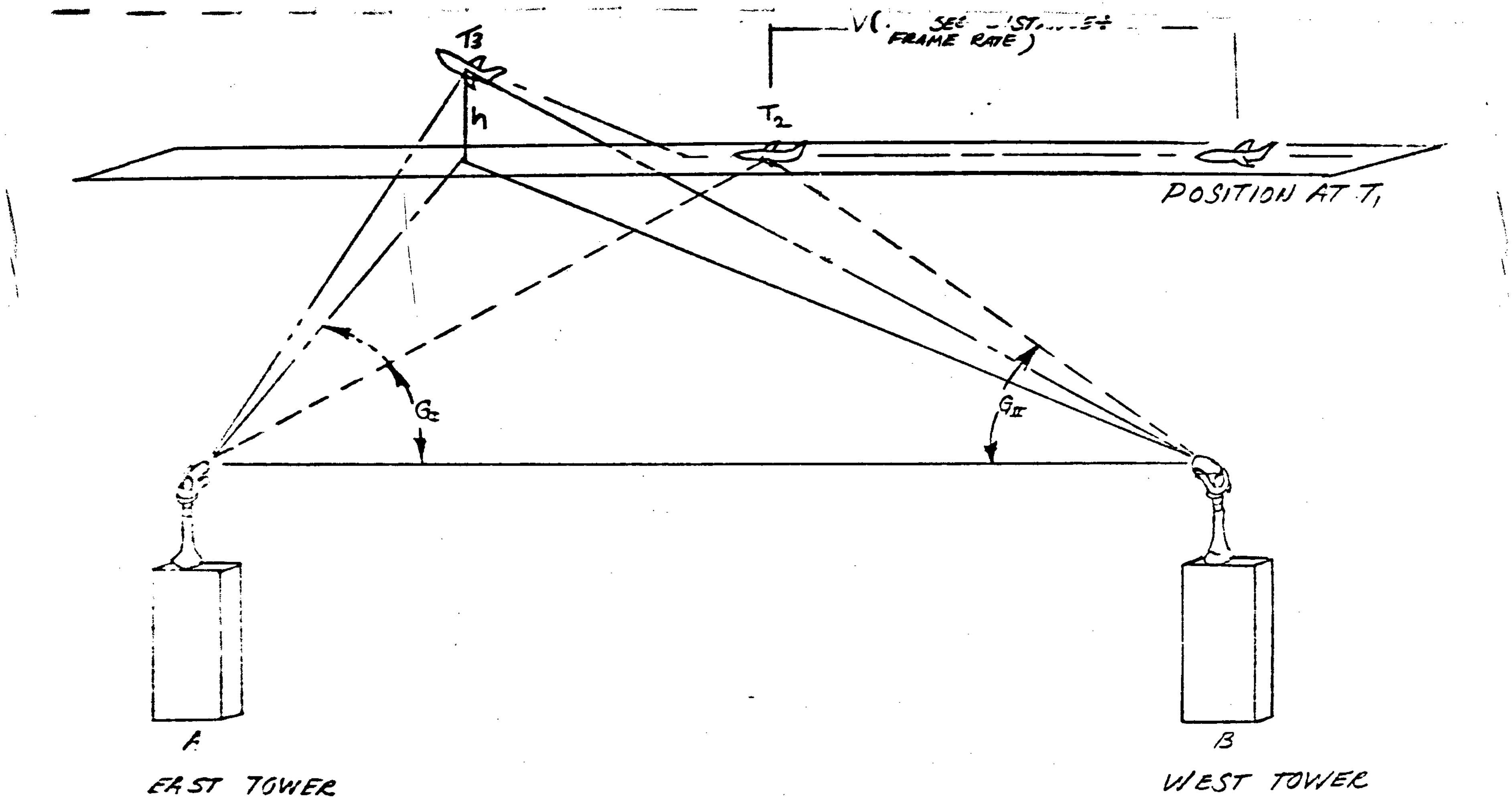


FIG 5 APPENDIX A
TYPICAL TWO STATION
THEODOLITE SOLUTION

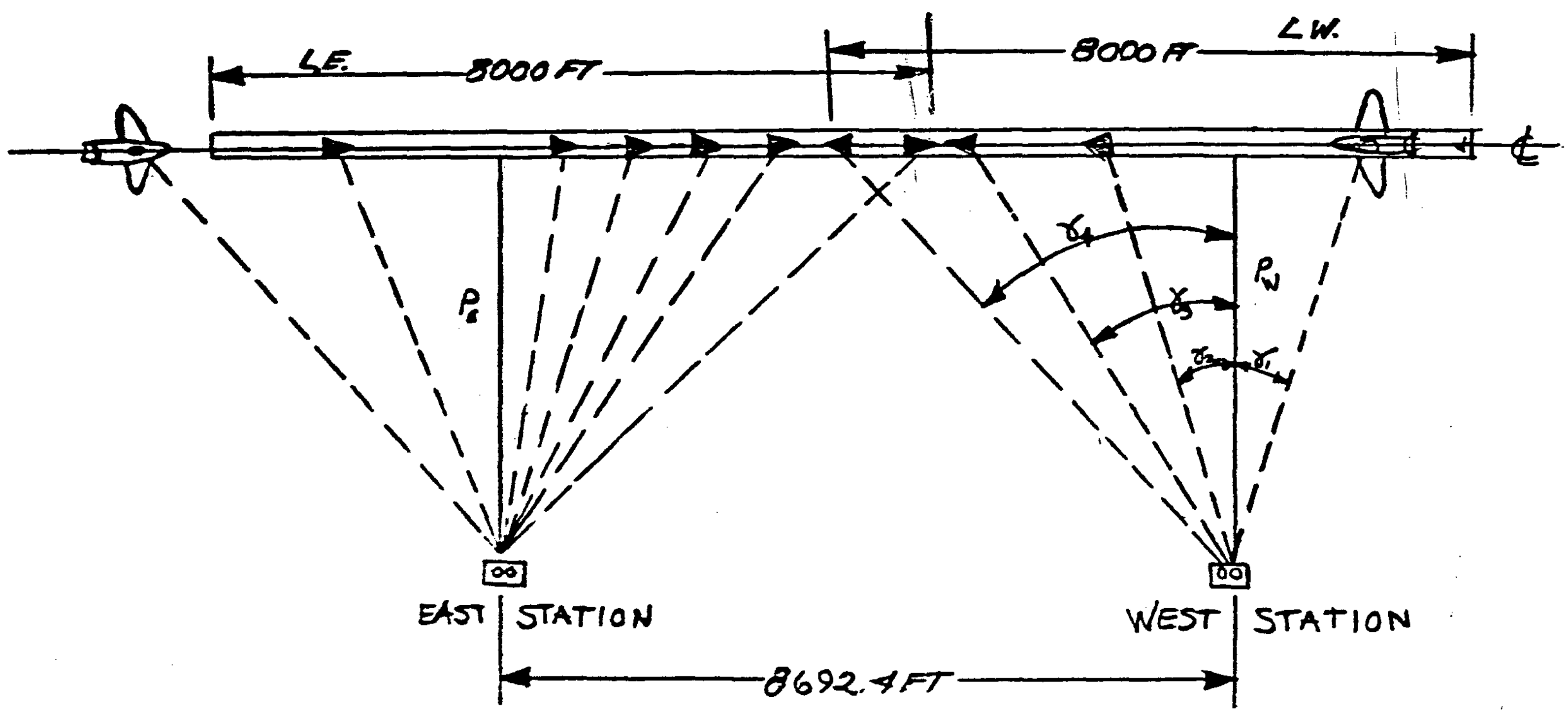


FIG 6
APPENDIX A

LE-SINGLE STA LIMIT USING EAST STA
LW-SINGLE STA LIMIT USING WEST STA.
P_E-LINE FROM EAST PEDESTAL EAST STA PERPENDICULAR TO ℄ OF RUN WAY
P_W-LINE FROM WEST PEDESTAL WEST STA. PERPENDICULAR TO ℄ OF RUNWAY

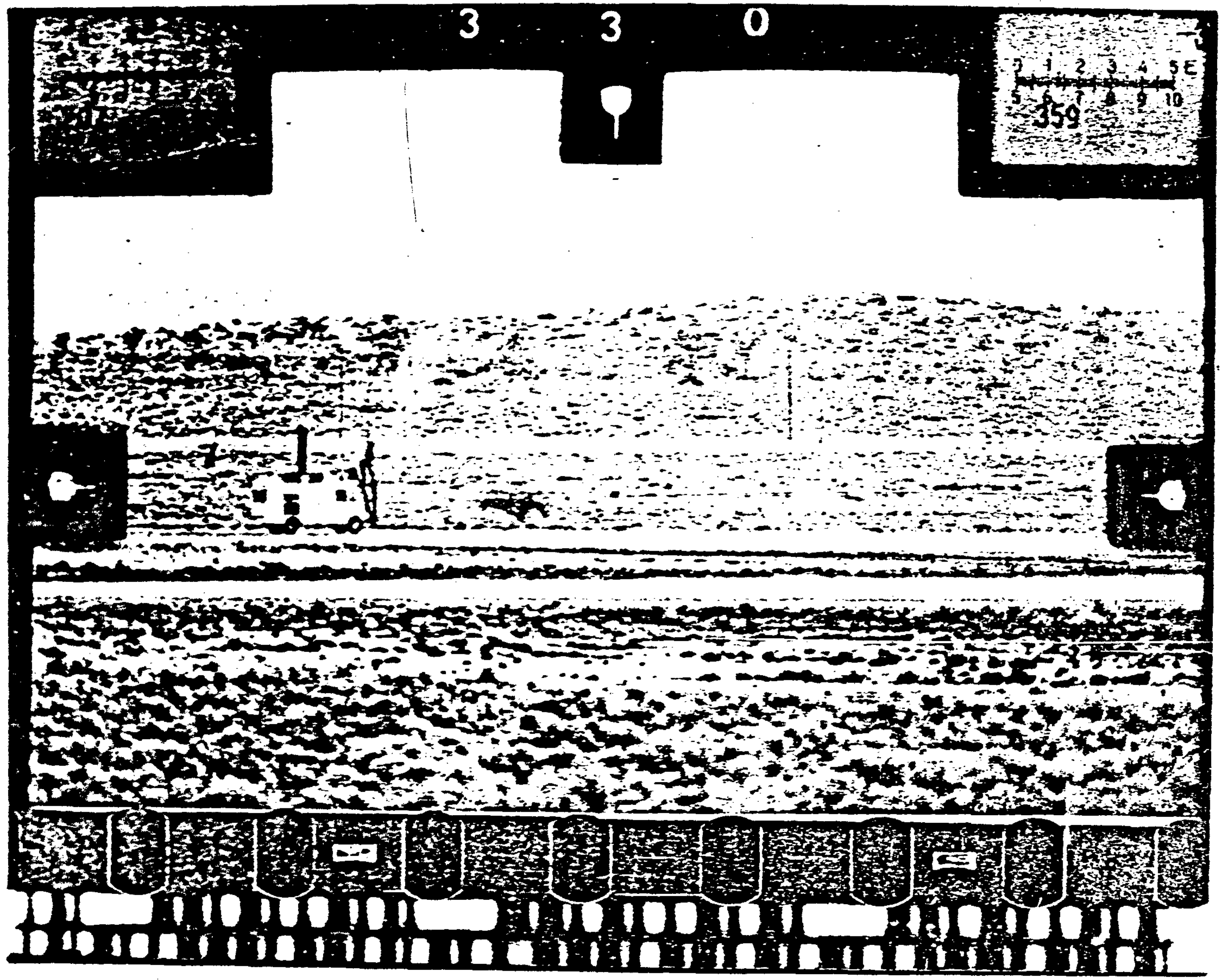


FIGURE 7, APPENDIX A
ASKANIA CINE-THEODOLITE FRAME
TARGET OFFSET FROM CENTER OF FRAME

APPENDIX B

SURVEY DATA

WEST PEDESTAL OF WEST TOWER

SEE PAGES	SEA LEVEL ELEVATION	PERPENDICULAR DIST TO & RUNWAY	LAMBERT COORDINATES Y	LAMBERT COORDINATES X	GEODETIC POSITION LAT	GEODETIC POSITION LONG
4, 58, 32	2343.871	5164.00	513,392.64	2,028,419.37	34°54'38.537"	117°54'18.752"

OBSERVED STATIONS

STATION	LAMBERT COORDINATES Y	LAMBERT COORDINATES X	GEODETIC AZIMUTH	GRID DISTANCE	GROUND DISTANCE	ELEVATION	VERTICAL DIST TO HORIZONTAL PLANE	SEE PAGES
WEST LEVEL TARGET	510,724.68	2,025,439.18	48° 13' 02. 125"	4000.000	4,000.740	2307.759	36.49'	48, 55, 4
WEST PERPENDICULAR	509,994.42	2,030,529.36	328° 13' 02. 125"	4000.000	4,000.739	2301.120	43.13'	49, 55, 4
CENTER	512,576.48	2,034,043.87	278° 19' 42. 199"	5681.303	5,682.353	2296.842	47.79'	45, 55, 4

EAST PEDESTAL OF WEST TOWER

SEE PAGES	SEA LEVEL ELEVATION	PERPENDICULAR DIST TO & RUNWAY	LAMBERT COORDINATES Y	LAMBERT COORDINATES X	GEODETIC POSITION LAT	GEODETIC POSITION LONG
4, 58, 52	2344.435	5164.06	513,396.91	2,028,426.20	34° 54' 38.579"	117° 54' 18. 670"

OBSERVED STATIONS

STATION	LAMBERT COORDINATES Y	LAMBERT COORDINATES X	GEODETIC AZIMUTH	GRID DISTANCE	GROUND DISTANCE	ELEVATION	VERTICAL DIST TO HORIZONTAL PLANE	SEE PAGES
WEST LEVEL TARGET	510,724.60	2,025,439.18	48° 14' 12. 952	4007.933	4008.674	2307.759	37.06	48, 54, 4
WEST PERPENDICULAR	509,994.42	2,030,529.36	328° 19' 58. 252	4000.028	4000.766	2301.120	43.70'	49, 54, 4
CENTER	512,576.48	2,034,043.87	278° 21' 46.938	5677.264	5678.312	2296.842	48.35'	45, 54, 4

WEST PEDESTAL EAST TOWER

SEE PAGES	SEA LEVEL ELEVATION	PERPENDICULAR DIST TO & RUNWAY	LAMBERT COORDINATES Y	LAMBERT COORDINATES X	GEODETIC POSITION LAT	GEODETIC POSITION LONG
4, 58, 51	2319.513	5164.37	517,972.96	2,035,795.46	34° 55' 23. 767"	117° 52' 50. 118"

OBSERVED STATIONS

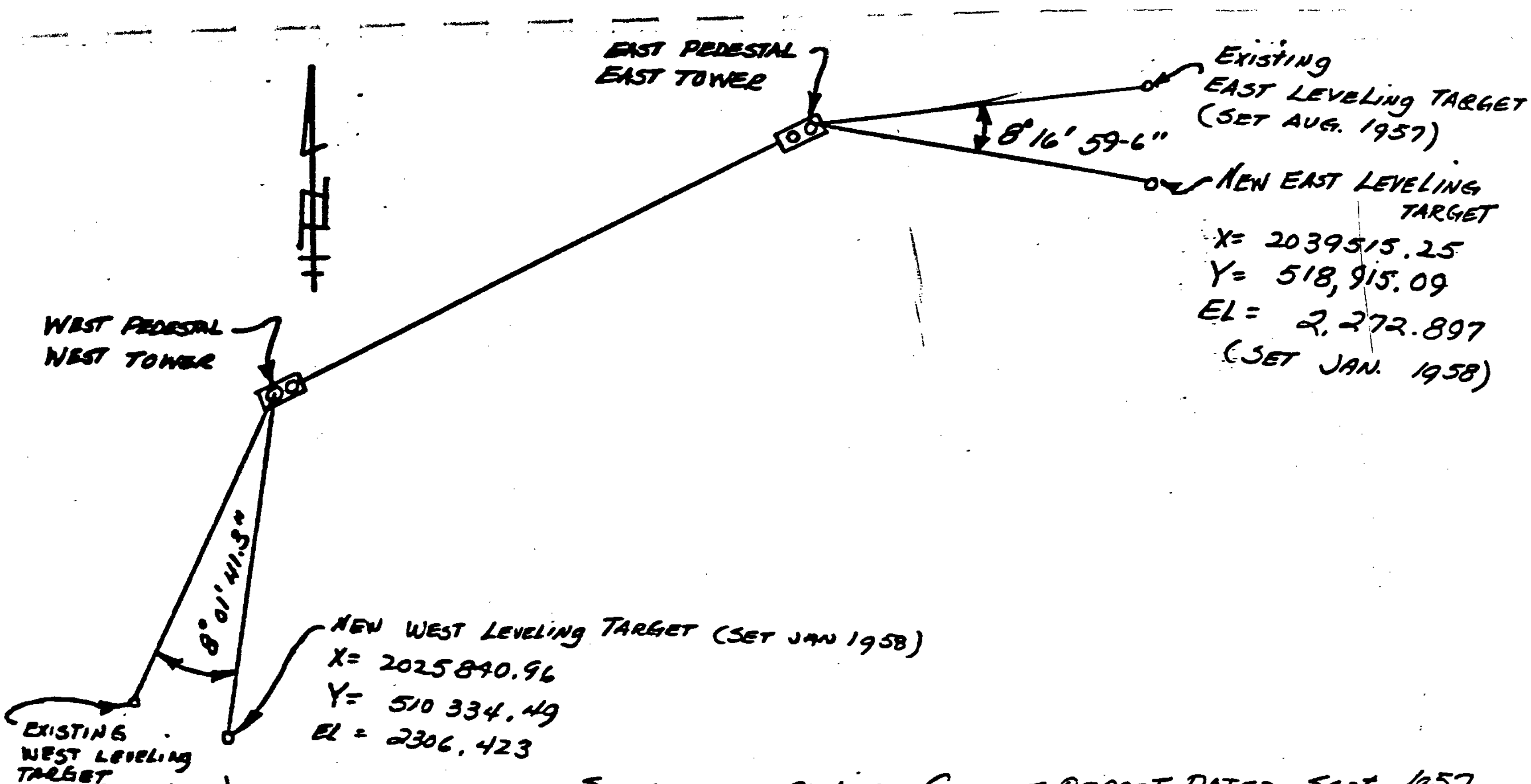
STATION	LAMBERT COORDINATES Y	LAMBERT COORDINATES X	GEODETIC AZIMUTH	GRID DISTANCE	GROUND DISTANCE	ELEVATION	VERTICAL DIST TO HORIZONTAL PLANE	SEE PAGES
EAST LEVEL TARGET	519,465.12	2,039,515.25	248° 12' 37. 171"	4007.915	4008.649	2272.964	46.33'	47, 56, 4
EAST PERPENDICULAR	514,579.21	2,037,912.43	328° 06' 45. 987	3999.888	4000.623	2285.814	33.48'	46, 56, 4
CENTER	512,576.48	2,034,043.87	18° 03' 01. 674	5673.629	5674.673	2296.842	22.84'	45, 56, 4

EAST PEDESTAL EAST TOWER

SEE PAGES	SEA LEVEL ELEVATION	PERPENDICULAR DIST TO & RUNWAY	LAMBERT COORDINATES Y	LAMBERT COORDINATES X	GEODETIC POSITION LAT	GEODETIC POSITION LONG
4, 58, 34, 27	2318.917	5164.44	517,977.27	2,035,802.26	34° 55' 23. 810"	117° 52' 50. 037"

OBSERVED STATIONS

STATION	LAMBERT COORDINATES Y	LAMBERT COORDINATES X	GEODETIC AZIMUTH	GRID DISTANCE	GROUND DISTANCE	ELEVATION	VERTICAL DIST TO HORIZONTAL PLANE	SEE PAGES
EAST LEVEL TARGET	519,465.12	2,039,515.25	248° 13' 52. 694	4000.00	4000.734	2272.964	46.93	47, 57, 4
EAST PERPENDICULAR	514,579.21	2,037,912.43	328° 13' 52. 694	4000.00	4000.736	2285.814	34.08	46, 57, 4
CENTER	512,576.48	2,034,043.87	18° 07' 12. 619	5681.937	5682.983	2296.842	23.43	45, 57, 4



SUPPLEMENT TO PG 1 OF CONTRACT REPORT, DATED SEPT. 1957

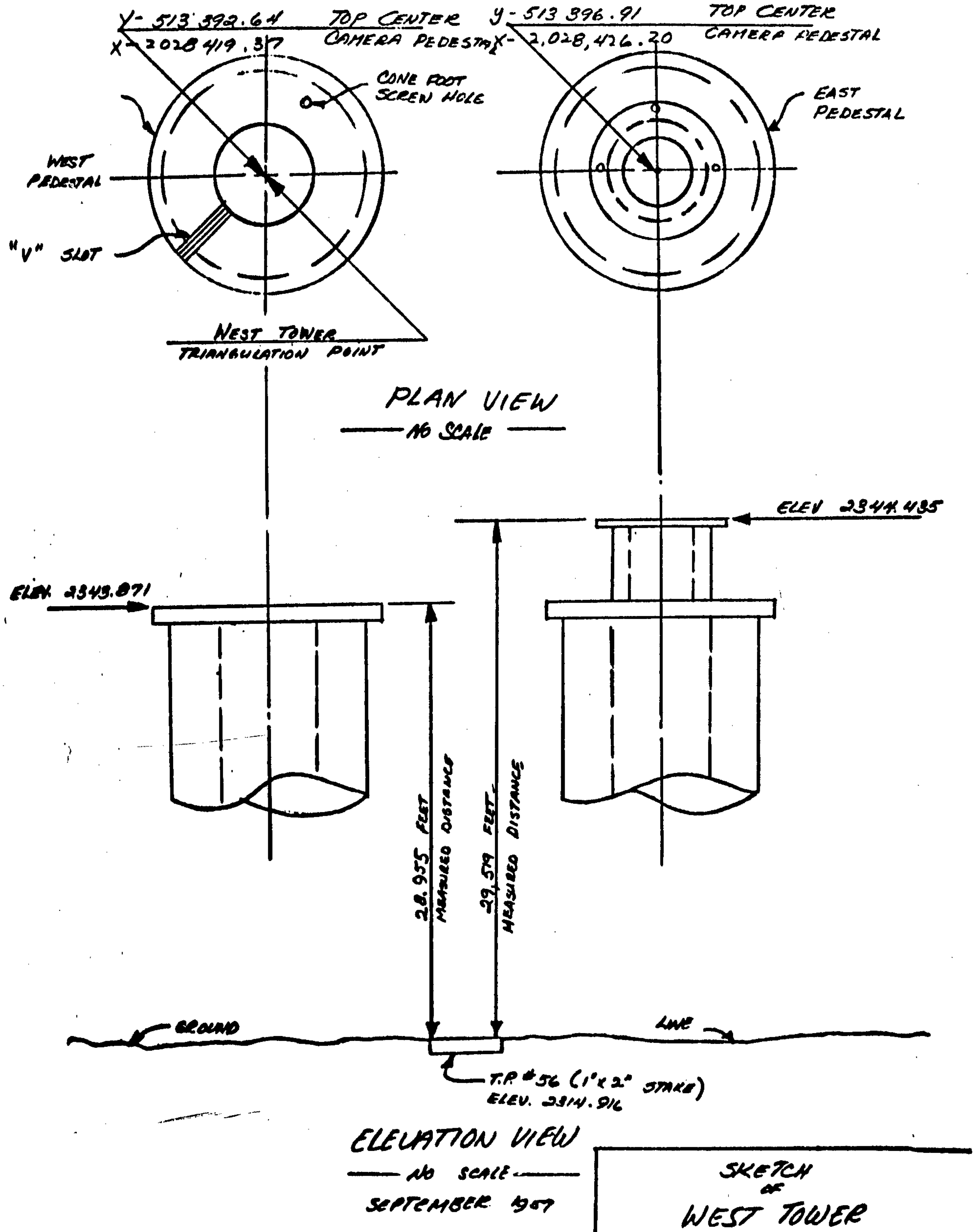
STATION	LAMBERT COORDINATES Y	X	GEODETIC AZIMUTH	GRID DISTANCE	GROUND DISTANCE	ELEVATION	VERT. DIST TO HORIZ. PLANE
NEW WEST L.T.	510334.49	2025840.96	40°11'20-8" ①	4000.07 ①	4000.81 ①	2306.423	37.83 ①
NEW EAST L.T.	518915.09	2039515.25	256°30'52.3" ②	4001.74 ②	4002.47 ②	2272.897	46.40 ②

① FROM WEST PEDESTAL
WEST TOWER

② FROM ~~WEST~~ EAST PEDESTAL
EAST TOWER

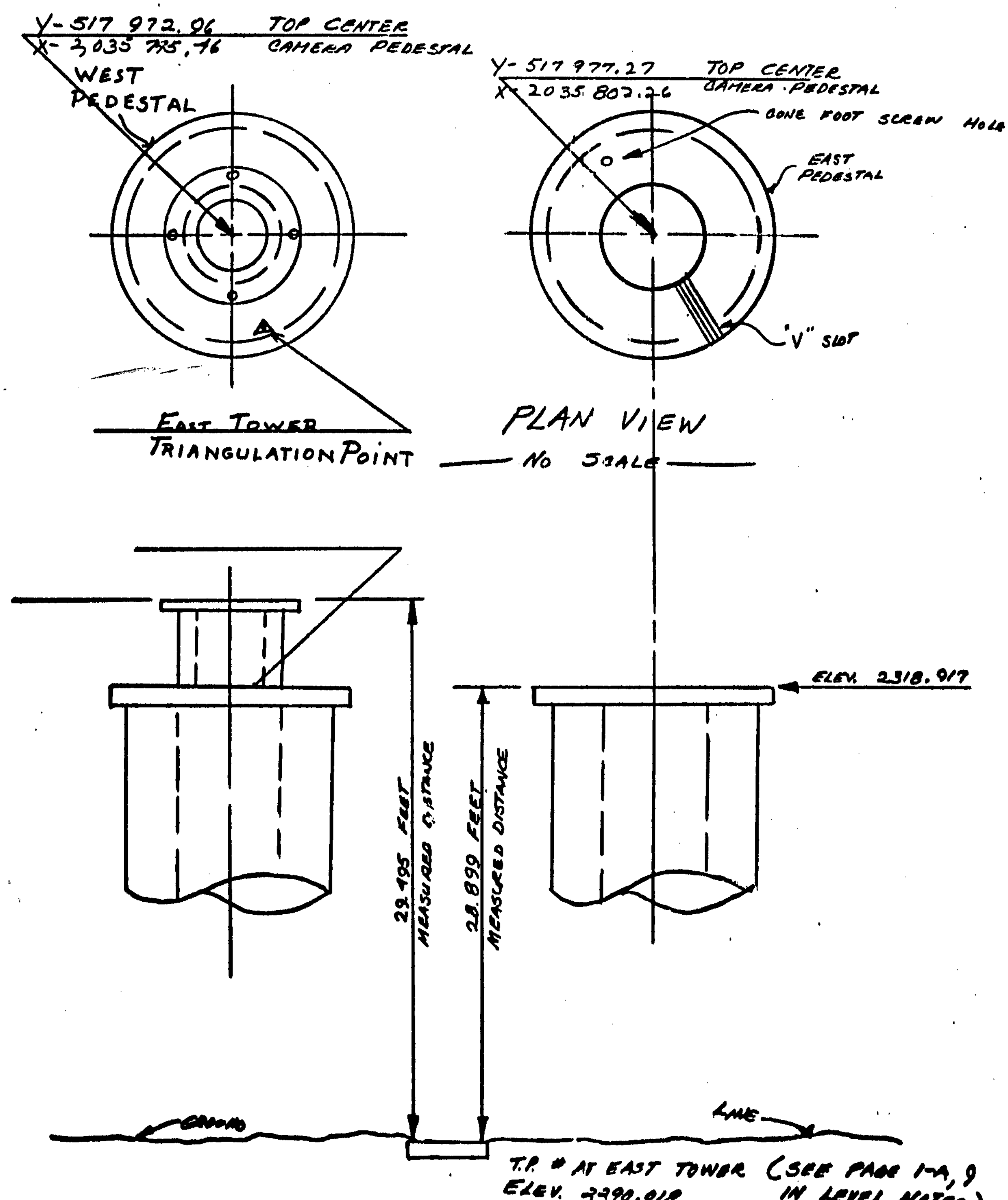
NEW LOCATIONS
OF
EAST AND WEST
LEVELING TARGETS

FIG 2, APPENDIX B



SKETCH
OF
WEST TOWER
CAMERA PEDESTALS

FIG. 3, APPENDIX B

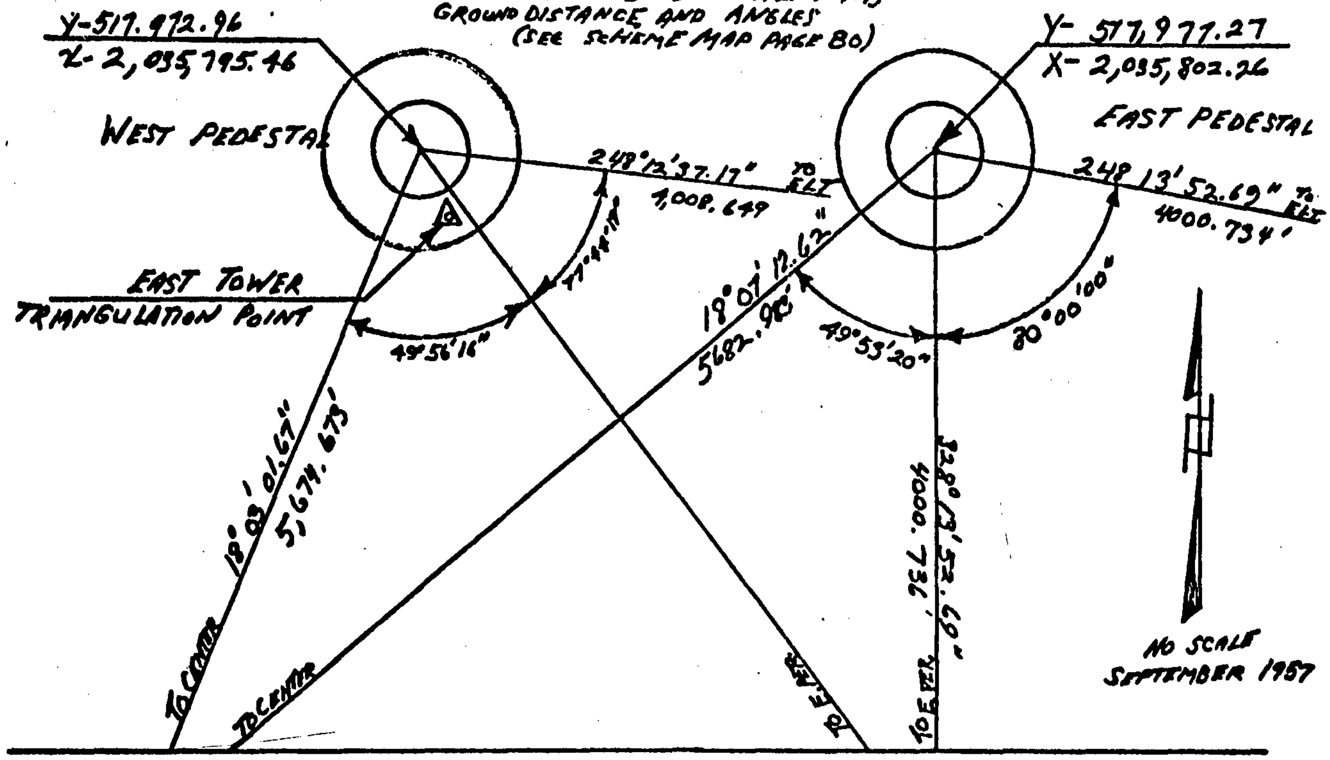


ELEVATION VIEW
— NO SCALE —
SEPTEMBER

SKETCH OF EAST TOWER CAMERA PEDESTALS

FIG 4 APPENDIX B

SKETCH
OF
EAST TOWER
SHOWING GEODETIC AZIMUTHS
GROUND DISTANCE AND ANGLES
(SEE SCHEME MAP PAGE 80)



SKETCH
OF
WEST TOWER
SHOWING GEODETIC AZIMUTHS
GROUND DISTANCE AND ANGLES
(SEE SCHEME MAP PAGE 80)

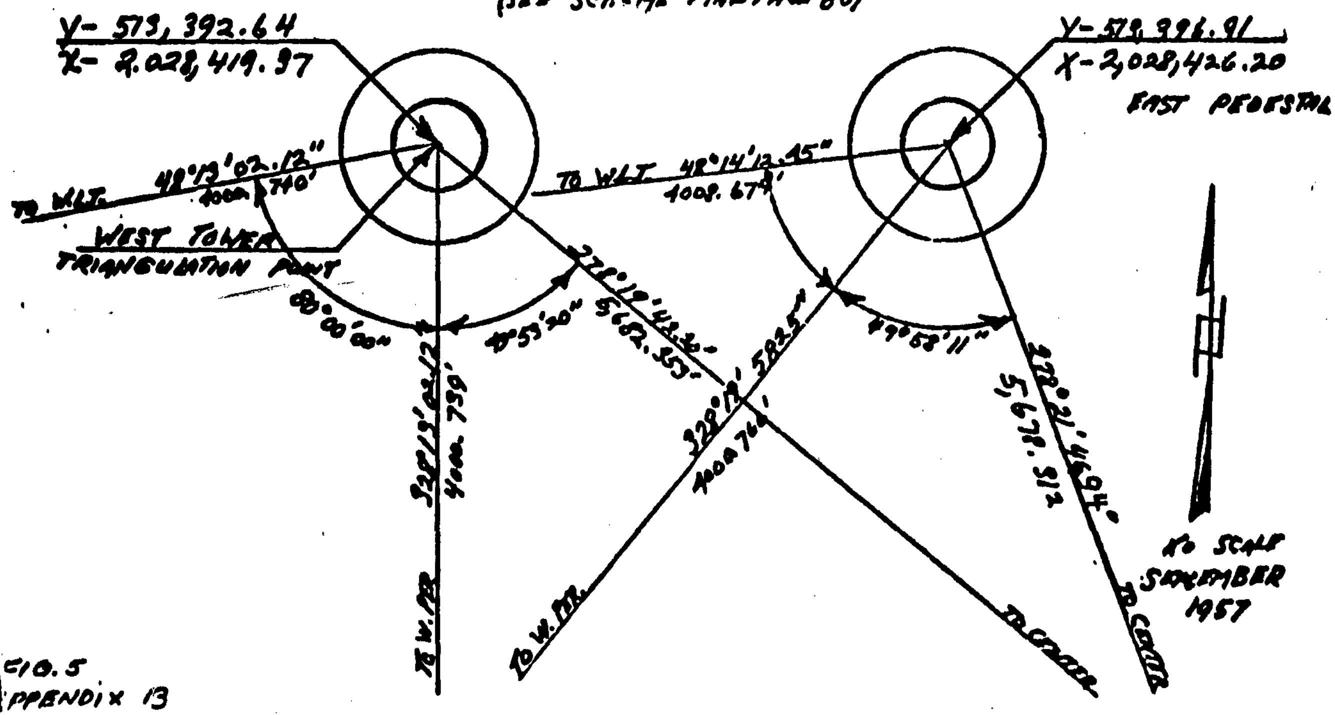
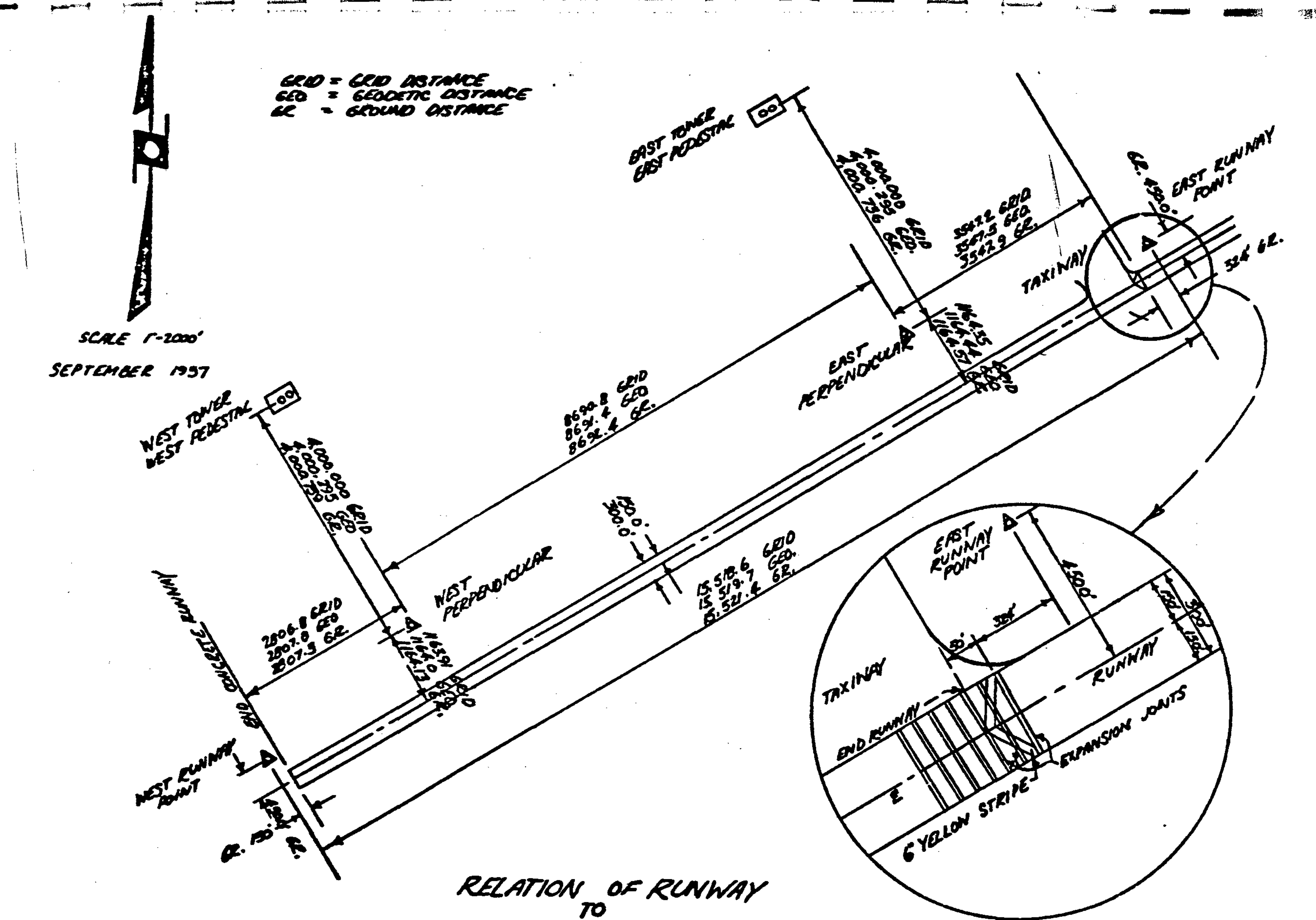


FIG. 5
APPENDIX 13



RELATION OF RUNWAY TO SCHEME STATIONS

FIG. 6 APPENDIX B

APPENDIX C

TABULAR AND GRAPHICAL DATA

FROM/TO	MEASURED DISTANCE	2 STA. ASKANIA	ERROR	2 STA. AKELEY	ERROR	WEST ASKANIA
0 - 1	1025.41	1024.90	+ .51	1021.77	-3.64	1025.57
1 - 2	999.66	999.75	+ .09	998.06	-1.60	999.23
2 - 3	999.84	1000.10	+ .26	999.24	- .60	994.07
3 - 4	1000.50	999.48	-1.02	1001.17	- .33	1006.47
4 - 5	999.50	999.30	- .20	999.16	- .34	999.23
5 - 6	1000.00	999.86	- .14	1000.28	+ .28	1000.27
6 - 7	999.84	999.36	- .48	999.86	+ .02	999.23
7 - 8	1000.41	1000.89	+ .48	999.36	-1.05	1001.30
8 - 9	999.75	999.11	- .64	999.36	- .39	998.73
9 - 10	1000.08	999.34	- .74	999.90	- .18	999.75
10 - 11	1000.16	999.54	- .62	999.25	- .91	999.75
11 - 12	1000.16	1000.32	+ .16	1000.37	+ .21	1000.78
12 - 13	999.59	998.09	-1.50	997.27	-2.32	998.20
13 - 14	1000.08	999.49	- .59	1001.99	+1.91	1000.27
14 - 15	800.00	799.29	- .71	799.32	- .68	800.42
			AVG 0.54 MAX 1.50		AVG 0.96 MAX 3.64	AVG W 8K

ERROR	EAST ASKANIA	ERROR	WEST AKELEY	ERROR	EAST AKELEY	ERROR
+ .16	1024.62	- .79	1030.23	+4.82	1024.61	- .80
- .43	999.84	+ .18	1001.31	+1.65	999.31	- .35
-5.77	999.83	- .01	995.96	-3.88	999.82	- .02
+5.97	998.32	-2.18	999.76	- .74	1000.85	+ .35
- .27	1000.32	+ .82	1000.28	+ .78	998.79	- .71
+ .27	999.84	- .16	998.73	-1.27	1000.34	+ .34
- .61	999.83	- .01	1000.28	+ .44	999.31	- .53
+ .89	1000.87	+ .46	998.21	-2.20	1000.33	- .08
-1.02	999.32	- .43	999.25	- .50	999.31	- .44
- .33	1000.87	+ .79	1000.27	+ .19	999.82	- .26
- .41	999.32	- .84	999.25	- .91	999.82	- .34
+ .62	1000.35	+ .19	1000.28	+ .12	999.83	- .33
-1.39	998.80	- .79	997.69	-1.90	999.30	- .29
+ .19	1001.90	+1.82	1001.83	+1.75	1000.34	+ .26
+ .42	802.04	+2.04	800.43	+ .43	803.58	+3.58
1.25		AVG .77		1.38		0.57
5.97		MAX 2.18		4.82		3.58
0.66	AVG E 8K	0.57	AVG W 8K	1.00	AVG E 8K	0.40

TABULAR LISTING OF DISTANCES BETWEEN DATA POINTS
AS COMPUTED BY ONE AND TWO STATION SOLUTIONS

FIGURE 1 APPENDIX C

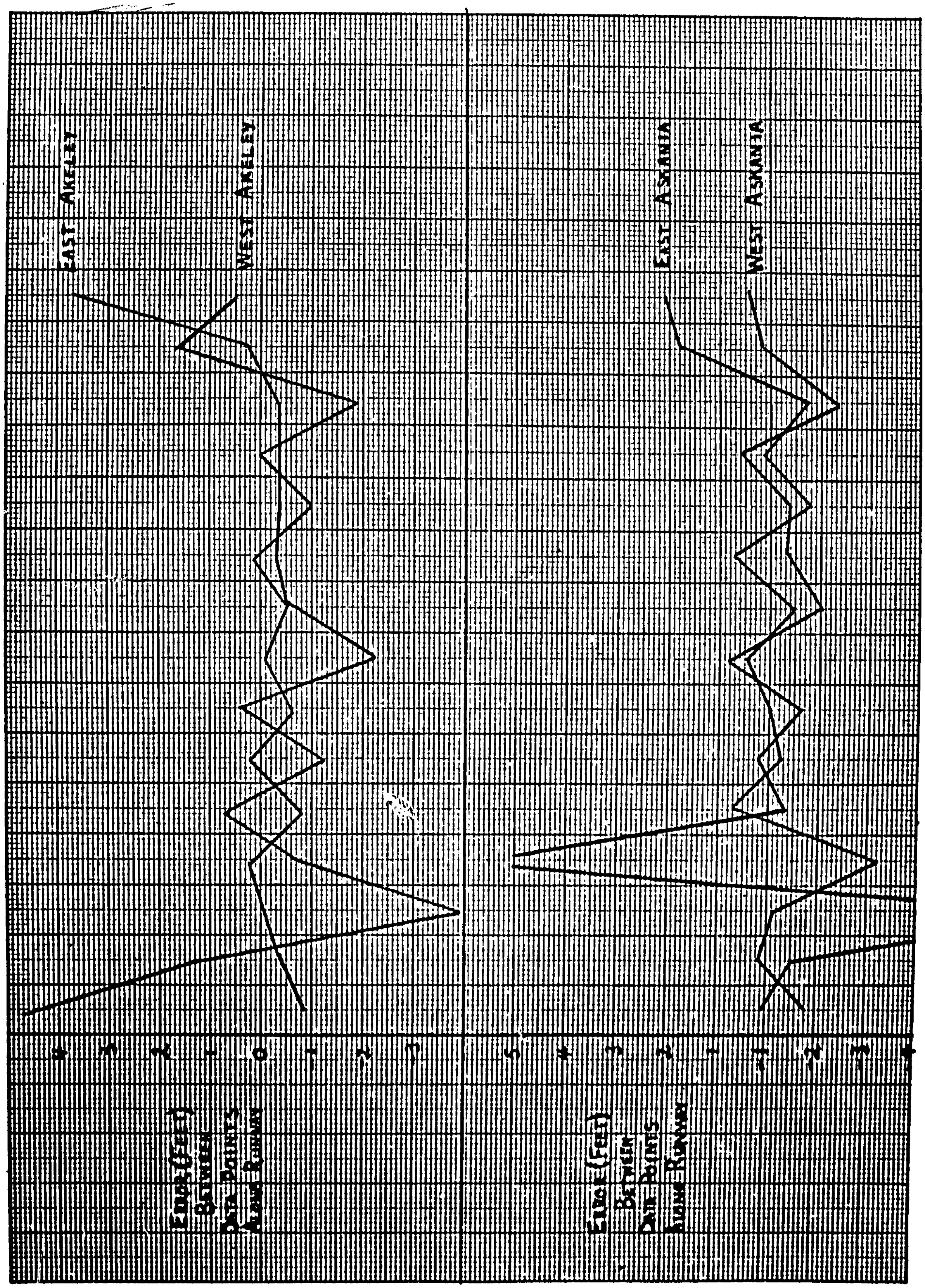


FIG 1
APPENDIX C

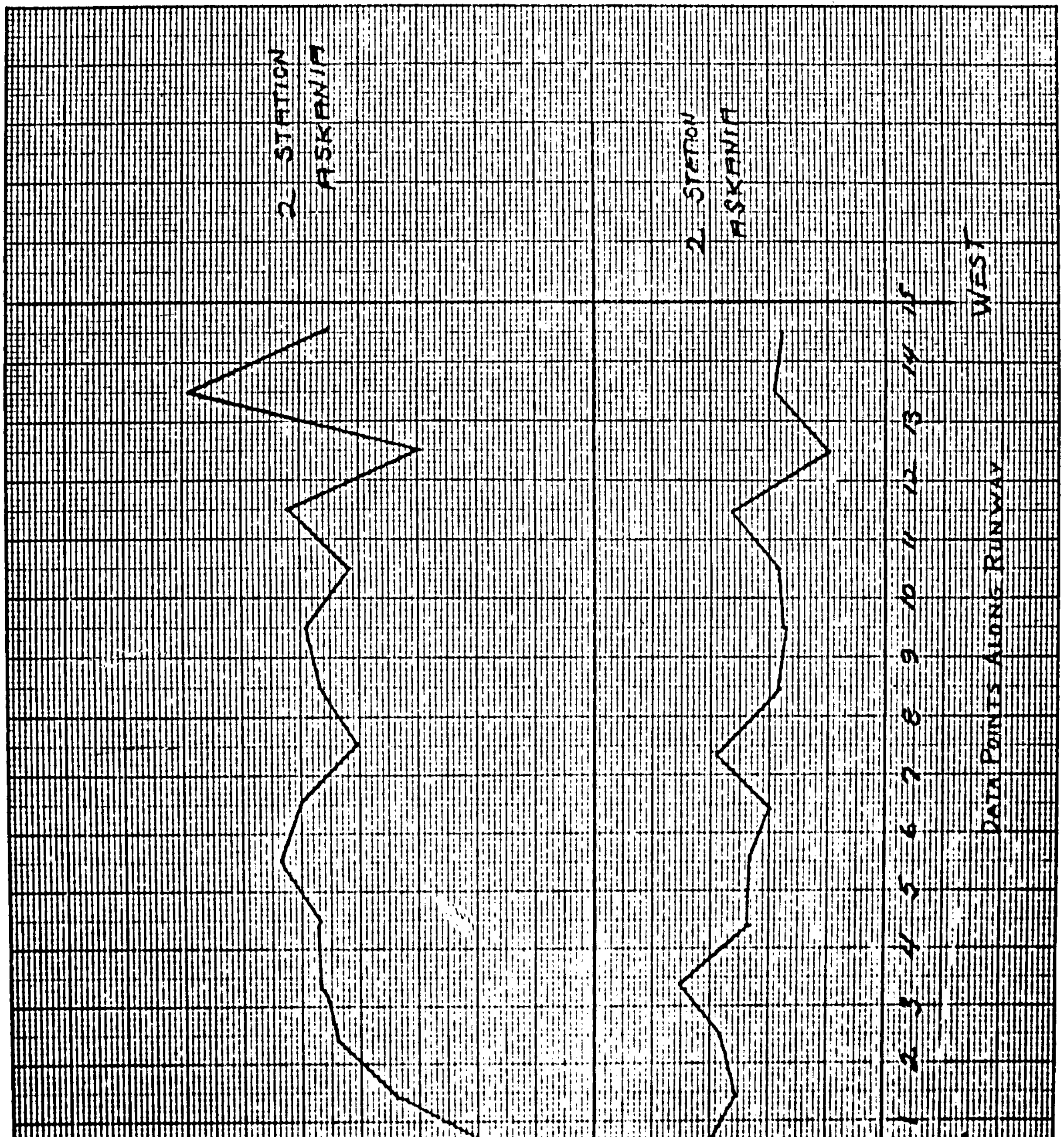


FIGURE 2 APPENDIX C

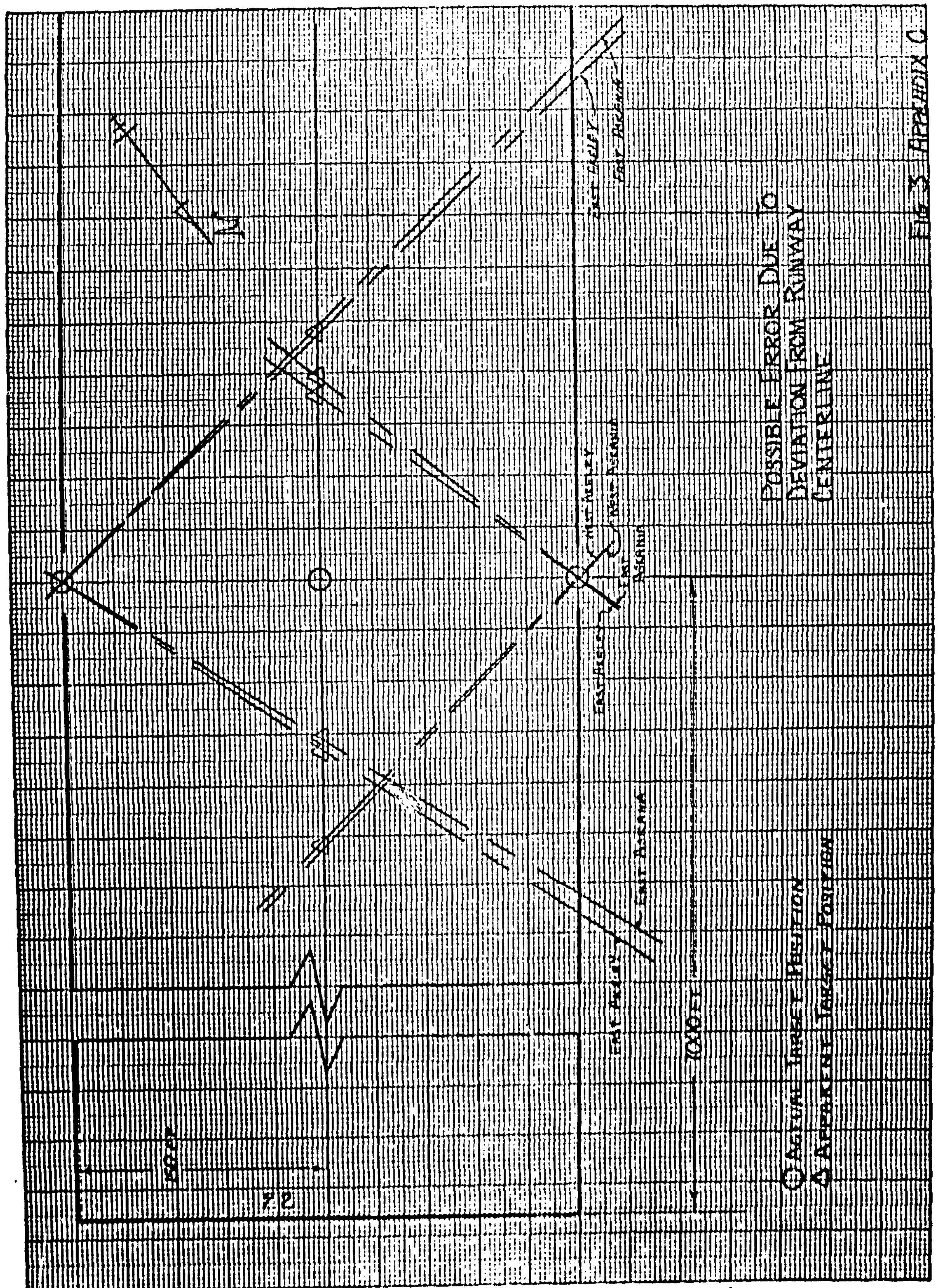


FIG 3
APPENDIX C

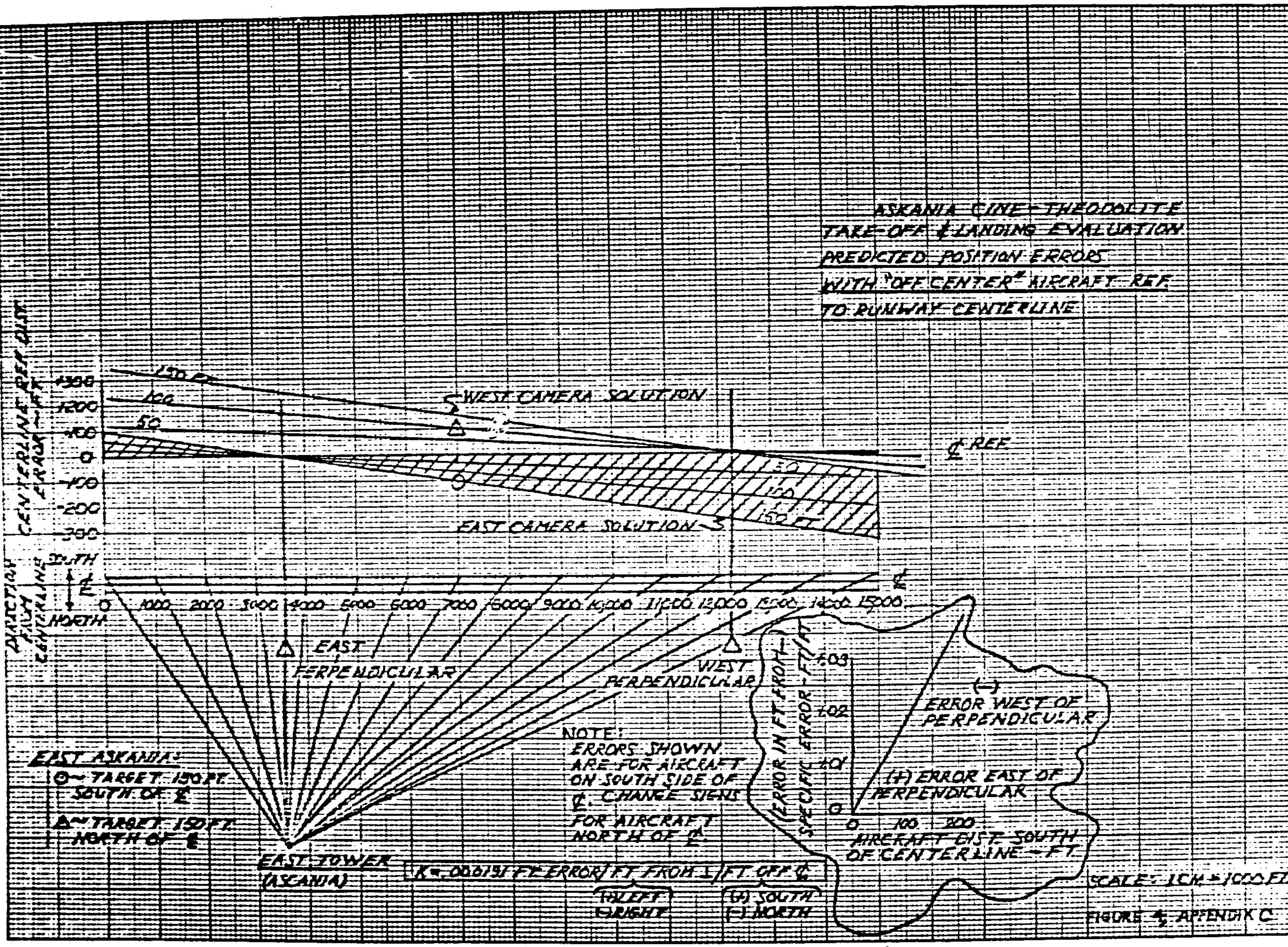


FIG 5
APPENDIX 2

ELEVATION COMPARISONS - 2 STATION SOLUTIONS

Data Point	Ground * Elevation	LOWER LIGHT ** Askania	LOWER LIGHT ** Akeley	UPPER LIGHT*** Askania	UPPER LIGHT*** Akeley
0	2281.0	+3.60	+2.4	+3.0	+2.6
1	2282.4	+3.27	+1.9	+3.3	2.1
2	2283.8	+3.35	+1.8	+3.1	1.8
3	2285.2	+3.23	+1.5	+3.2	1.6
4	2286.6	+3.01	+1.7	+2.8	1.5
5	2288.0	+3.41	+1.9	+2.9	1.8
6	2289.4	+3.27	+1.8	+3.0	1.8
7	2290.8	+3.22	+2.1	+3.5	2.1
8	2292.2	+3.22	+2.5	+3.2	3.0
9	2293.6	+3.49	+3.1	+3.3	3.3
10	2295.0	+3.22	+3.6	+3.3	3.6
11	2296.4	+3.57	+3.6	+3.8	3.6
12	2297.8	+3.30	+3.4	+3.2	3.4
13	2299.2	+3.33	+4.1	+2.7	4.3
14	2300.6	+3.08	+3.3	+3.9	3.4
15	2302.0	+2.72	+5.6	+3.5	4.1
		Avg 3.268	Avg 2.8	Avg 3.23	Avg2.71

ELEVATION COMPARISONS - 2 STATION SOLUTIONS

* Constant slope of 0.140% assumed
** Adjusted 9.5 ft, height of light above runway
*** " 19.5 " " " " " "

Figure 5
Appendix C

RUNWAY SLOPE - FEET/1000 FEET OF RUNWAY

	2-STATION ASKANIA	2-STATION AKELEY	WEST ASKANIA	EAST ASKANIA	WEST AKELEY	EAST AKELEY
Data Point #0, East	0	0	0	0	0	0
1	1.07	0.90	1.20	0	1.34	-0.19
2	1.48	1.30	1.27	3.40	1.66	0.85
3	1.28	1.10	1.40	0.17	1.75	0.27
4	1.18	1.60	1.66	2.41	1.20	1.63
5	1.80	1.60	1.21	0.78	1.78	0.92
6	1.26	1.30	1.17	-0.23	1.12	1.27
7	1.35	1.70	1.55	3.54	1.34	1.70
8	1.40	1.80	1.19	1.52	1.51	1.72
9	1.67	2.00	1.61	1.12	1.13	2.39
10	1.13	1.90	0.96	1.31	1.30	2.13
11	1.75	1.40	1.47	1.70	0.99	1.31
12	1.13	1.20	1.13	0.67	1.09	0.92
13	1.43	2.10	1.45	1.23	1.54	2.36
14	1.15	0.60	1.11	1.52	0.68	0.17
15	1.04	2.70	1.23	0.37	1.09	3.59

Figure 6
Appendix C

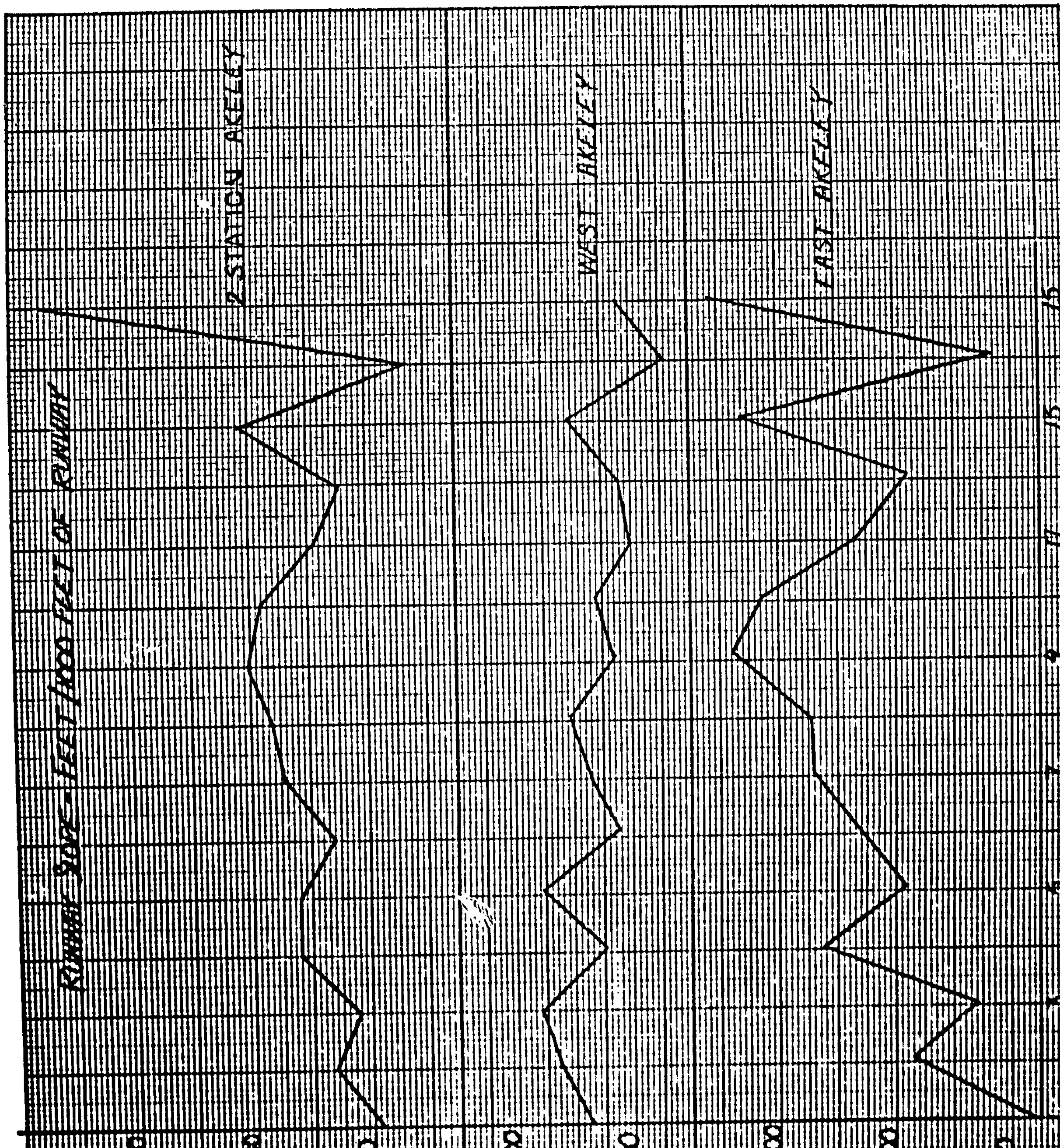


FIG 6
APPENDIX C

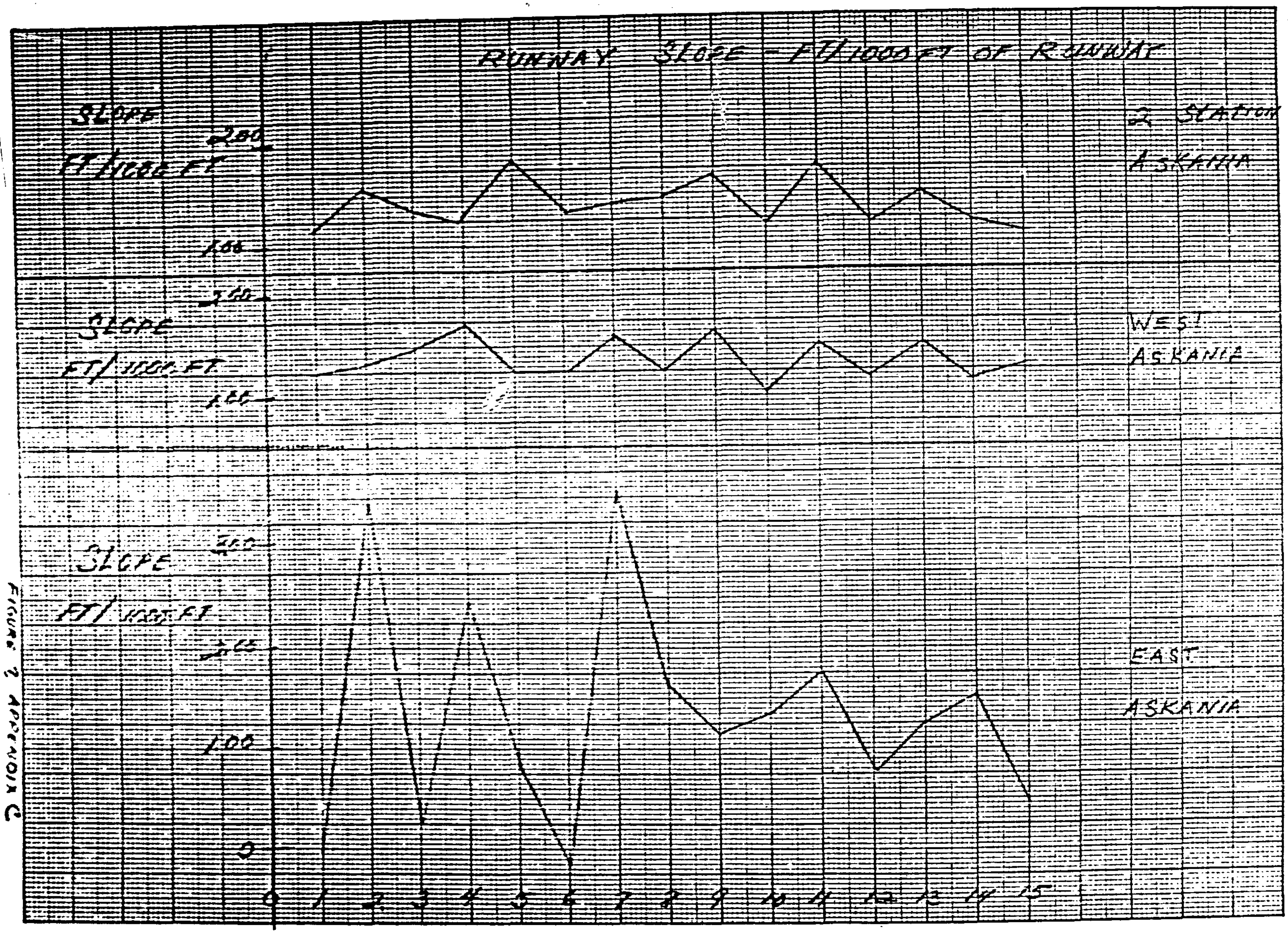


FIGURE 2 APPENDIX C

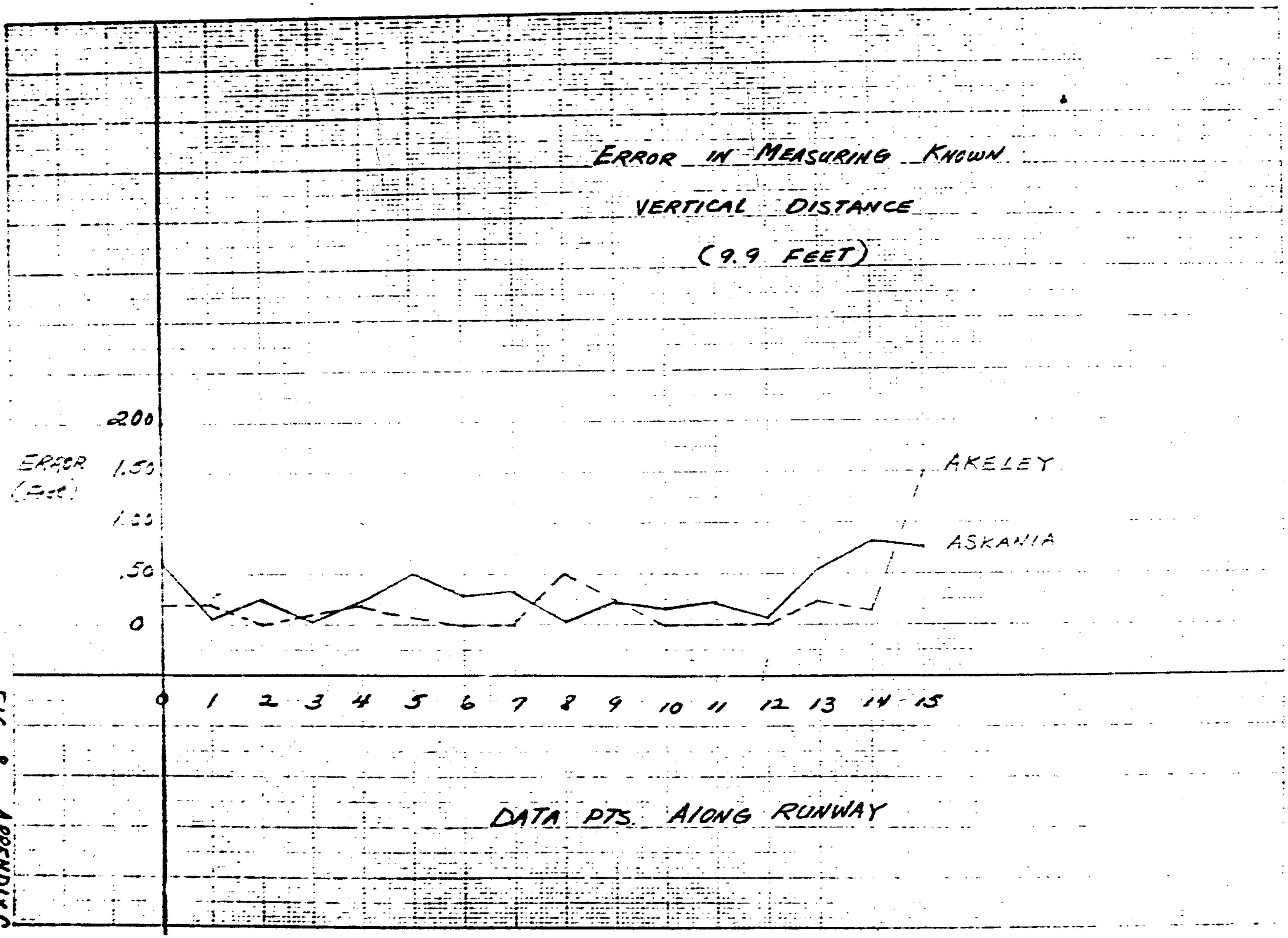


FIG. 8, APPENDIX C

Data Point	TWO STATION SOLUTIONS Askania #1	Askania #2	Askania #3	Askania #4	SINGLE STATION SOLUTIONS West Askania	East Askania
#1	43.75		43.67	43.59	43.89	43.38
2	43.34		43.52	43.41	43.38	43.38
3	43.67	43.73	43.60	43.76	43.38	43.90
4	43.43	43.19	43.47	-	44.41	42.86
5	43.51	43.62	43.29	-	43.38	43.90
6	43.01	43.12	43.15	43.11	42.86	43.38
7	43.29	43.00	43.26	43.28	43.38	43.90
8	43.87	43.13	42.95	42.96	42.34	42.86
9	43.35	43.32	43.22	43.50	43.38	43.38
10	43.38	43.30	43.40	43.09	44.41	42.86
11	43.35	43.33	43.43	43.37	42.86	43.90
12	43.81	43.82	43.65	43.69	43.89	43.38
13	43.18	43.28	43.41	43.35	42.86	43.90
14	43.70	43.72	43.59	43.70	44.42	43.38
15	43.70	43.84	43.92	43.85	43.37	43.89
16	43.18	43.95	43.00	42.88	43.38	42.87
17	43.68	43.65	43.71	43.93	43.89	43.90
18	-	-	-	-	42.87	-
19	-	-	-	-	42.86	-
20	43.13	43.33	43.09	43.48	43.86	43.89
21	43.84	43.62	43.94	43.49	42.89	43.90
22	43.42	43.38	43.29	43.68	42.38	43.90
23	43.67	43.60	43.75	43.56	42.89	43.90
24	43.67	43.87	43.81	43.73	42.90	43.38
25	43.11	42.97	43.10	43.04	42.86	42.86
26	42.76	42.89	42.87	42.72	43.38	42.87
27	42.60	42.32	42.44	42.55	41.82	42.86
28	41.26	41.62	[illegible].37	41.22	41.32	41.84
29	42.12	-	41.82	41.93	42.34	42.34
30	40.65	-	40.78	40.84	40.80	40.29

	TWO STATION SOLUTIONS			SINGLE STATION SOLUTIONS	
Akeley #1	Akeley #2	Akeley #3	Akeley #4	West Akeley	East Akeley
43.75	43.55	43.55	43.62	42.86	44.41
43.77	43.85	44.01	43.99	44.41	43.90
45.05	44.95	44.79	44.77	44.93	44.41
42.44	42.54	42.50	42.52	43.89	41.32
43.26	43.25	43.33	43.24	41.83	44.93
43.17	43.05	43.17	43.03	42.86	42.86
42.23	42.32	42.12	42.39	41.83	43.38
44.23	44.34	44.75	44.32	44.93	43.38
43.87	43.85	43.55	43.85	43.38	44.42
42.85	42.68	42.59	42.76	43.37	42.35
42.18	42.90	42.83	42.73	42.87	42.34
43.41	42.93	43.00	42.88	42.34	43.38
44.95	44.63	44.74	44.86	45.44	44.42
43.05	43.17	43.24	43.16	42.87	43.89
43.94	43.85	43.69	43.84	43.37	44.42
41.54	41.65	41.56	41.64	42.87	40.28
45.91	46.02	46.20	45.87	45.96	45.45
42.33	42.06	42.09	42.40	42.86	42.34
43.53	43.58	43.62	43.50	42.34	44.93
43.28	43.35	43.33	43.33	42.35	44.42
45.29	44.75	45.14	45.17	45.44	44.93
42.31	42.87	42.27	42.21	42.35	42.35
42.97	42.85	42.86	42.90	42.86	43.38
44.02	44.22	44.28	44.28	43.89	44.93
43.67	43.72	43.63	43.74	44.93	41.31
42.49	42.54	42.65	42.34	42.35	42.87
41.71	41.40	41.57	41.56	40.79	42.86
41.22	41.37	41.60	41.48	40.80	42.35
43.35	42.92	42.95	42.81	43.89	41.31
40.33	40.70	40.26	40.77	41.32	40.29

VELOCITY COMPUTATIONS

FIGURE 9 APPENDIX C

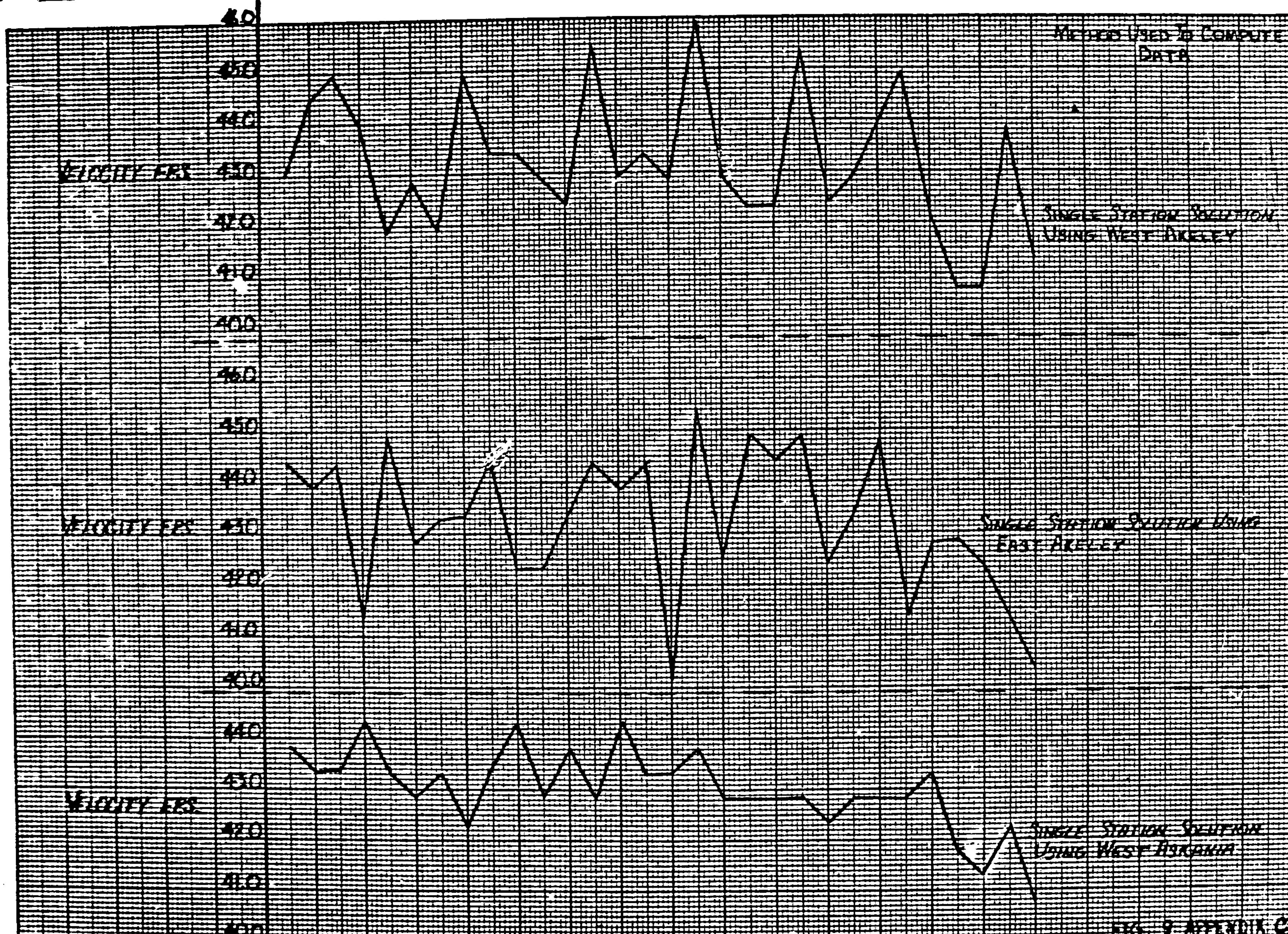


FIG. 9 APPENDIX C

Velocity vs. Time

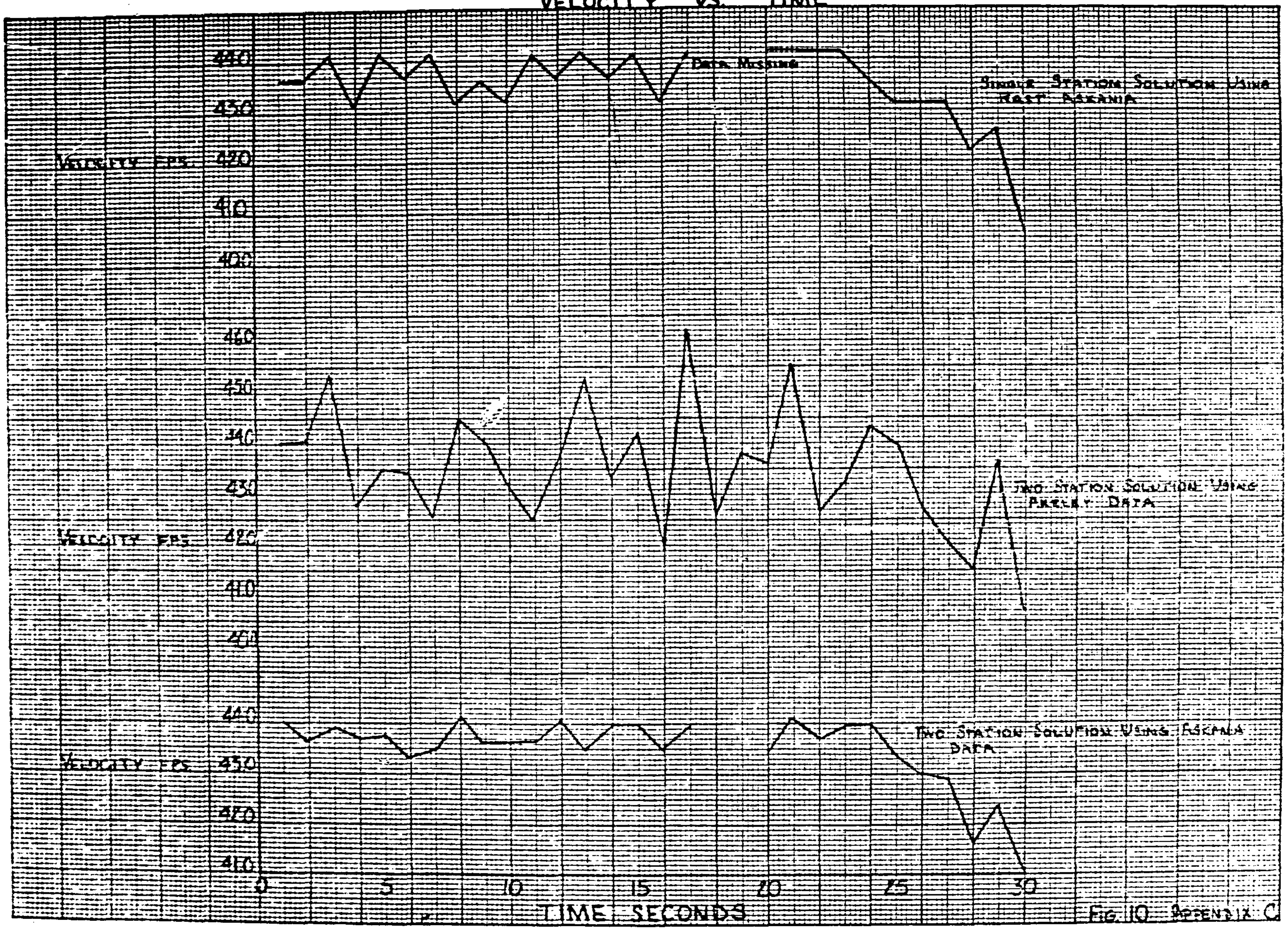


Fig. 10 Appendix C

APPENDIX D

DATA REDUCTION PROCEDURES

Single Station Askania or Akeley Solution

Multiple Cine-Theodolite Position Reduction

APPENDIX D

SINGLE STATION ASKANIA OR AKELEY SOLUTION

The employment of single station solution of take-off and/or landing data requires that several facts be assumed as stated previously in this memorandum.

The following formulae are used for single station solutions:

DISTANCE (along runway) = tan (azimuth angle - Orientation angle) x theodolite offset

HEIGHT (above take-off or touchdown) $= \dfrac{\tan \text{Elevation angle}}{\cos (\text{Azimuth angle} - \text{orientation angle})}$ x theodolite offset

DISTANCE (along runway) is the distance along the centerline of the runway measured from a point on the centerline from which a perpendicular line would pass through the center of the west pedestal in the West Tower.

AZIMUTH AND ELEVATION ANGLES are dial readings plus tracking and leveling corrections.

ORIENTATION ANGLE is corrected azimuth angle to the orientation target located on a line originating at the tower and being perpendicular to the centerline of the runway.

THEODOLITE OFFSET is horizontal distance from the center of the theodolite to a point on the centerline of the runway which, if connected, would be perpendicular to the centerline.

HEIGHT is referenced to the point of take-off or touchdown.

MULTIPLE CINE-THEODOLITE POSITION REDUCTION

1. Zero Point corrections for the azimuth and elevation dials and a collimation correction (the distance between the center of the film frame and the intersection of the lens axis with the film frame), are computed from shots of the targets. The target shots are made with the theodolites in direct and inverted positions.

2. The zero point corrections are added to the azimuth and elevation dial readings of each frame.

3. The X and Y tracking corrections in film reading machine counts are converted to actual distance in millimeters on the film frame. They measure the distance of the object being tracked from the center of the film. Next, the tracking corrections, t_{AZ} and t_{EL} in radians are computed and added to the Az and El angles.

$$t_{AZ} = \frac{X_{mm}}{F_{mm}} \sec El\left(1 + \frac{Y_{mm}}{F_{mm}} \tan El\right)$$

$$t_{EL} = \frac{Y_{mm}}{F_{mm}} - \frac{\left(\frac{X_{mm}}{F_{mm}}\right)^2 \tan EL}{2}$$

F is the focal length of the lens.

4. Corrections for earth curvature, C_{AZ} and C_{EL} are next computed and added to the Az and El angles.

$$C_{AZ} = \alpha \sin (Az - \Theta) \tan El$$

$$C_{EL} = \alpha \cos (Az - \Theta)$$

α is the angle between the theodolite and the zero point of the range measured at the center of the earth. Θ is the angle to the origin measured at the theodolite.

5. Given these corrected Az and El angles, an approximate position of the object is computed. The refraction of air correction is computed and added to the elevation angle.

$$r = -\frac{Ad}{ah^2} e^{-ah'} (ah + e^{-ah} - 1)$$

A is a constant 2.77×10^{-4}

a is a constant 3.16×10^{-5}

h is the height of the object above the theodolite (Δ altitude)

h' is the altitude of the theodolite, MSL d is the horizontal distance from the theodolite to the object.

r is the refraction correction in radians

6. The final XYZ is computed from the Az and El of all cameras.

given: from each of n theodolites where i is a theodolite number, $1 \leq i \leq n$; Az_i, El_i, X_i, Y_i, Z_i

to find: the closest approximation to the location of the object tracked X_o, Y_o, Z_o

solve: Three simultaneous linear equations

$$\sum_{i=1}^{n} (1-j_i^2)X_o + \sum_{i=1}^{n} (-j_i m_i)Y_o + \sum_{i=1}^{n} (-j_i n_i)Z_o = \sum_{i=1}^{n} x_i - \sum_{i=1}^{n} j_i p_i$$

$$\sum_{i=1}^{n} (-j_i m_i)X_o + \sum_{i=1}^{n} (1-m_i^2)Y_o + \sum_{i=1}^{n} (-m_i n_i)Z_o = \sum_{i=1}^{n} y_i - \sum_{i=1}^{n} m_i p_i$$

$$\sum_{i=1}^{n} (-j_i n_i)X_o + \sum_{i=1}^{n} (-m_i n_i)Y_o + \sum_{i=1}^{n} (1-n_i^2)Z_o = \sum_{i=1}^{n} z_i - \sum_{i=1}^{n} n_i p_i$$

where: $j_i = \cos El_i \cos Az_i$

$m_i = \cos El_i \sin El_i$

$n_i = \sin El_i$

$p_i = j_i x_i + m_i y_i + n_i z_i$

These three equations are solved by a matrix routine.

7. Altitude MSL = $Z_o + \frac{d^2}{2R}$ where d is the horizontal distance of the object from range zero and R is the radius of the earth.

8. Velocity is a simple first difference.

$$\sqrt{\frac{\Delta x^2 + \Delta y^2 + \Delta z^2}{t}} = V$$

DISTRIBUTION:

FTP	2 cys
FTFE	1 cy
FTFEE	10 cys
FTFER	1 cy
FTFO	2 cys
FTFP	1 cy
FTFF	1 cy
FTFFP	7 cys
FTOP	1 cy
FTGT	1 cy

Plus fifty (50) additional copies